# Geophysical Image Processing with Seismic Unix: GPGN 461/561 Lab Fall 2011

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# Preface

I started writing these notes in 2005 to aid in the teaching of a seismic processing lab that is part of the courses Seismic Processing GPGN561 and Advanced Seismic Methods GPGN452 (later GPGN461) in the Department of Geophysics, Colorado School of Mines, Golden, CO.

In October of 2005, Geophysics Department chairman Terry Young, asked me if I would be willing to help teach the Seismic Processing Lab. This was the year following Ken Larner's retirement. Terry was teaching the lecture, but decided that the students should have a practical problem to work on. The choice was between data shot in the Geophysics Field Camp, the previous summer, or the Viking Graben dataset, which Terry had brought with him from his time at Carnegie Mellon University. We chose the latter, and decided that the students should produce as their final project, a poster presentation similar to those seen at the SEG annual meeting. Terry seemed to think that we could just hand the students the SU User's Manual, and the data, and let them have at it. I felt that more needed to be done to instruct students in the subject of seismic processing, while simultaneously introducing them to the Unix operating system, shell language programming, and of course Seismic Unx.

In the years that have elapsed my understanding of the subject of seismic processing has continued to grow, and in each successive semester, I have gathered more examples, and figured out how to apply more types of processing techniques to the data.

My vision of the material is that we are replicating the seismic processors' base experience, such as a professional would have obtained in the petroleum industry in the late 1970s. The idea is not to train students in a particular routine of processing, but to teach them how to think like geophysicists. Because seismic processing techniques are not exclusively used on petroleum industry data, the notion of "geophysical image processing" rather than simply "seismic" processing is conveyed.

# Chapter 1

# Seismic Processing Lab- Preliminary issues

## 1.1 Motivation for the lab

In the lecture portion of the course GPGN452/561 (now GPGN461/561) (Advanced Seismic Methods/Seismic Processing) the student is given a word, picture, and chalkboard introduction of the process of seismic data acquisition and the application of a myriad of processing steps for converting raw seismic data into a scientifically useful picture of the earth's subsurface.

This lab is designed to provide students with a practical hands-on experience in the *reality* of applying seismic processing techniques to synthetic and real data. The course, however, is not a "training course in seismic processing," as one might get in an industrial setting. Rather than training a student to use a particular collection of software tools, we believe that it is better that the student cultivate a broader understanding of the subject of seismic processing. We seek also to help students develop some practical skills that will serve them in a general way, even if they do not go into the field of oil and gas exploration and development.

Consequently, we make use of freely available open-source software (the Seismic Unix package) running on small-scale hardware (Linux-based PCs). Students are also encouraged to install the SU software on their own personal (Linux or Mac) PCs, so that they may work (and play) with the data and with the codes at their leisure.

Given the limited scale of our available hardware and time, our goal is modest, to introduce students to seismic data processing through a 2D single-component processing application.

The intended range of experience is approximately that which a seismic processor of the late 1970s would have experienced on a vastly slower, more expensive, and more difficult to use processing platform.

## 1.2 Unix and Unix-like operating systems

The Unix operating system (as well as any other Unix-like operating system, which includes the various forms of Linux, UBUNTU, Free BSD Unix, and Mac OS X) is commonly used in the exploration seismic community. Consequently, learning aspects this operating system is time well spent. Many users may have grown up with a "point and click" environment where a given program is run via a graphical user interface (GUI) featuring menus and assorted windows. Certainly there are such software applications in the world of commercial seismic processing, but none of these are inexpensive, and none give the user access to the source code of the application.

There is also an "expert user" level of work where such GUI-driven tools do not exist, however, and programs are run from the commandline of a terminal window or are executed as part of a processing sequence in shell script.

In this course we will use the open source CWP/SU:Seismic Unix (called simply Seismic Unix or SU) seismic processing and research environment. This software collection was developed largely at the Colorado School of Mines (CSM) at the Center for Wave Phenomena (CWP), with contributions from users all around the world. The SU software package is designed to run under any Unix or Unix-like operating system, and is available as full source code. Students are free to install Linux and SU on their PCs (or use Unix-like alternatives) and thus have the software as well as the data provided for the course for home use, during, and beyond the time of the course.

### 1.2.1 Steep learning curve

The disadvantage that most beginning Unix users face is a steep learning curve owing to the myriad commands that comprise Unix and other Unix-like operating systems. The advantages of software portability and flexibility of applications, as well as superior networking capability, however, makes Unix more attractive to industry than Microsoft-based systems for these expert level applications. While a user in an industrial environment may have a Microsoft-based PC on his or her desk, the more computationally intensive processing work is done on a Unix-based system. The largest of these are clusters composed of multi-core, multiprocessor PC systems. It is not uncommon these days for such systems to have several thousand "cores," which is to say subprocessors, available.

Because a course in seismic processing is of broad interest and may draw students with varied backgrounds and varied familiarity with computing systems, we begin with the basics. The reader familiar with these topics may skip to the next chapter.

## 1.3 Logging in

As with most computer systems, there is a prompt, usually containing the word "login" or the word "username" that indicates the place where the user logs in. The user is then prompted for a password. Once on the system, the user either has a windowed user

interface as the default, or initiates such an interface with a command, such as **startx** in Linux.

## 1.4 What is a Shell?

Some of the difficult and confusing aspects of Unix and Unix-like operating systems are encountered at the very beginning of using the system. The first of these is the notion of a *shell*. Unix is an hierarchical operating system that runs a program called the *kernel* that is is the heart of the operating system. Everything else consists of programs that are run by the kernel and which give the user access to the kernel and thus to the hardware of the machine.

The program that allows the user interfaces with the computer is called the "working shell." The basic level of shell on all Unix systems is called **sh**, the *Bourne shell*. Under Linux-based systems, this shell is actually an open-source rewritten version called **bash** (the Bourne again shell), but it has an alias that makes it appear to be the same as the **sh** that is found on all other Unix and Unix-like systems.

The common working shell environment that a user is usually set up to login in under may be **csh** (the C-shell), **tcsh** (the T-shell, which is a non proprietary version of **csh**, **ksh** (the Korn shell, which is proprietary), **zsh** which is an open source version of Korn shell, or **bash**, which is an open source version of the Bourne shell.

The user has access to an application called *terminal* in the graphical user environment, that when launched (usually by double clicking) invokes a window called a *terminal window*. (The word"terminal" harks back to an earlier day, when a physical device called a terminal consisting of a screen and keyboard (but no mouse) constituted the users' interface to the computer.) It is at the prompt on the terminal window that the user has access to a *commandline* where Unix commands are typed.

Most "commands" on Unix-like systems are not built in commands in the shell, but are actually programs that are run under the users' working shell environment. The shell commandline prompt is asking the user to input the name of an executable program.

## 1.5 The working environment

In the Unix world all filenames, program names, shells, and directory names, as well as passwords are case sensitive in their input, so please be careful in running the examples that follow.

If the user types:

```
$ cd                                    <--- change directory with no argument
^                                           takes the user to his/her home
(don't type the dollar sign)                 directory
```

In these notes, the $ symbol will represent the commandline prompt. The user does not type this $. Because there are a large variety of possible prompt characters, or strings of

characters that people use for the propmt, we show here only the dollar sign $ as a generic commmandline prompt. On your system it might be a %, a >, or some combination of these with the computer name and or the working directory and/or the commandline number.

```
$ echo $SHELL                          <--- returns the value of the users'
       ^                                     working shell environment
     type this dollar sign
```

The command **echo $SHELL** tells your working shell to return the value that denotes your working shell environment. In English this command might be translated as "print the value of the variable SHELL". In this context the dollar sign $ in front of SHELL should be translated as "value of".

Common possible shells are

```
/bin/sh                                <--- the Bourne Shell
/bin/bash                              <--- the Bourne again Shell
/bin/ksh                               <--- K-shell
/bin/zsh                               <--- Z-shell
/bin/csh                               <--- C-shell
/bin/tcsh                              <--- T-shell.
```

The environments **sh**, **bash**, ksh, and zsh are similar. We will call these the "sh-family." The environments csh and tcsh are similar to each other, but have many differences from the sh-family. We refer to csh and tcsh as the csh-family.

## 1.6 Setting the working environment

Each of these programs have a specific syntax, which can be quite complicated. Each is a language that allows the user to write programs called "shell scripts." Thus Unix-like systems have scripting languages as their basic interface environment. This endows Unix-like operating systems with vastly more flexibility and power than other operating systems you may have encountered.

With more flexibility and power, there comes more complexity. It is possible to perform many configuration changes and personalizations to your working environment, which can enhance your user experience. For these notes we concentrate only on enough of these to allow you to work effectively on the examples in the text.

## 1.7 Choice of editor

To edit files on a Unix-like system, the user must adopt an editor. The traditional Unix editor is **vi** or one of its non-proprietary clones **vim** (**vi**-improved), *gvim*, or **elvis**. The

**vi** environment has a steep learning curve making it often unpopular among beginners. If a person is envisioning working on Unix-like systems a lot, then taking the time to learn **vi** is also time well spent. The **vi** editor is the only editor that is guaranteed to be on all Unix-like systems. All other editors are third-party items that may have to be added on some systems, sometimes with difficulty.

Similarly there is an editor called **emacs** that is popular among many users, largely because it is possible to write programs in the LISP language and implement these within **emacs**. There is a steep learning curve for this language, as well. There is often substantial configuration required to get **emacs** working in the way the user desires.

A third editor is called **pico**, which comes with a mailer called "**pine**." **Pico** is easy to learn to use, fully menued, and runs in a terminal window.

The fourth class of editor consists of the "screen editors." Popular screen editors include **xedit**, **nedit**, and **gedit**. There is a windowed interfaced version of emacs called **xemacs** that is similar to the first two editors. These are all easy to learn and to use.

Not all editors are the best to use. The user may find that invisible characters are introduced by some editors, and that there may be issues regarding how wrapped lines are handled that may cause problems for some applications. (More advanced issues such as those which might be of interest to a Unix system administrator, narrow the field back to **vi**.)

The choice of editor is often a highly personal one depending on what the user is familiar with, or is trying to accomplish. Any of the above mentioned editors, or similar third party editors likely are sufficient for the purposes of this course.

## 1.8 The Unix directory structure

As with other computing systems, data and programs are contained in "files" and "files" are contained in "folders." In Unix and all Unix-like environments "folders" are called "directories."

The structure of directories in Unix is that of an upside down tree, with its root at the top, and its branches—subdirectories and the files they contain—extending downward. The root directory is called "/" (pronounced "slash").

While there exist graphical browsers on most Unix-like operating systems, it is more efficient for users working on the commandline of a terminal windows to use a few simple commands to view and navigate the contents of the directory structure. These commands **pwd** (print working directory), **ls** (list contents), and **cd** (change directory).

### Locating yourself on the system

If you type:

```
$ cd
$ pwd
$ ls
```

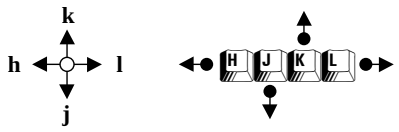
# Vi Quick Reference

http://www.sfu.ca/~yzhang/linux

## MOVEMENT

(**lines** - ends at <CR>; **sentence** - ends at puncuation-space; **section** - ends at <EOF>)

### By Character




### By Line

| | |
|---|---|
| ***n*G** | to line *n* |
| **0, $** | first, last position on line |
| **^ or _** | first non-whitespace char on line |
| **+, -** | first character on next, prev line |

### By Screen

| | |
|---|---|
| **^F**, **^B** | scroll foward, back one full screen |
| **^D**, **^U** | scroll forward, back half a screen |
| **^E**, **^Y** | show one more line at bottom, top |
| **L** | go to the bottom of the screen |
| **z↵** | position line with cursor at top |
| **z.** | position line with cursor at middle |
| **z-** | position line with cursor at |

### Marking Position on Screen

| | |
|---|---|
| **m*p*** | mark current position as *p* (a..z) |
| **`*p*** | move to mark position *p* |
| **'*p*** | move to first non-whitespace on line w/mark *p* |

### Miscellaneous Movement

| | |
|---|---|
| **f*m*** | forward to character *m* |
| **F*m*** | backward to character *m* |
| **t*m*** | forward to character before *m* |
| **T*m*** | backward to character after *m* |
| **w** | move to next word (stops at puncuation) |
| **W** | move to next word (skips punctuation) |
| **b** | move to previous word (stops at punctuation) |
| **B** | move to previous word (skips punctuation) |
| **e** | end of word (puncuation not part of word) |
| **E** | end of word (punctuation part of word) |
| **), (** | next, previous sentence |
| **]], [[** | next, previous section |
| **}, {** | next, previous paragraph |
| **%** | goto matching parenthesis () {} [] |

## EDITING TEXT

### Entering Text

| | |
|---|---|
| **a** | append after cursor |
| **A or $a** | append at end of line |
| **i** | insert before cursor |
| **I or _i** | insert at beginning of line |
| **o** | open line below cursor |
| **O** | open line above cursor |
| **c*m*** | change text (*m* is movement) |

### Cut, Copy, Paste (Working w/Buffers)

| | |
|---|---|
| **d*m*** | delete (*m* is movement) |
| **dd** | delete line |
| **D or d$** | delete to end of line |
| **x** | delete char under cursor |
| **X** | delete char before cursor |
| **y*m*** | yank to buffer (*m* is movement) |
| **yy or Y** | yank to buffer current line |
| **p** | paste from buffer after cursor |
| **P** | paste from buffer before cursor |
| **"*b*dd** | cut line into named buffer *b* (a..z) |
| **"*b*p** | paste from named buffer *b* |

### Searching and Replacing

| | |
|---|---|
| **/*w*** | search forward for *w* |
| **?*w*** | search backward for *w* |
| **/*w*/+*n*** | search forward for *w* and move down *n* lines |
| **n** | repeat search (forward) |
| **N** | repeat search (backward) |

| | |
|---|---|
| **:s/*old*/*new*** | replace next occurence of *old* with *new* |
| **:s/*old*/*new*/g** | replace all occurences on the line |
| **:*x*,*y*s/*old*/*new*/g** | replace all ocurrences from line *x* to *y* |
| **:%s/*old*/*new*/g** | replace all occurrences in file |
| **:%s/*old*/*new*/gc** | same as above, with confirmation |

### Miscellaneous

| | |
|---|---|
| ***n*>*m*** | indent *n* lines (*m* is movement) |
| ***n*<*m*** | un-indent left *n* lines (*m* is movement) |
| **.** | repeat last command |
| **U** | undo changes on current line |
| **u** | undo last command |
| **J** | join end of line with next line (at <cr>) |
| **:r*f*** | insert text from external file *f* |
| **^G** | show status |

Figure 1.1: A quick reference for the **vi** editor.

You will see that your current working directory location, which is your called your "home directory." You should see something like

```
$ pwd
/home/yourusername
```

where "yourusername" is your username on the system. Other users likely have their home directories in

```
/home
```

or something similar, depending on how your system administrator has set things up. The command **ls** will show you the contents of your home directory, which may consist of files or other subdirectories.

The codes for Seismic Unix are installed in some system directory path. We will assume that all of the CWP/SU: Seismic Unix codes are located in

```
/usr/local/cwp
```

This denotes a directory "cwp," which is the sub directory of a directory called "local," which is in turn a directory of the directory "usr," that itself is a sub directory of slash.

It is worth wile for the user to spend some time learning the layout of his or her directories. There is a command called

```
$ df
```

which shows the hardware devices that constitute the available storage on the users' machine. A typical output from typing "df"

```
Filesystem           1K-blocks      Used Available Use% Mounted on
/dev/sda1            295101892  45219392 234892216  17% /
none                   4070496       268   4070228   1% /dev
none                   4075032      4988   4070044   1% /dev/shm
none                   4075032       124   4074908   1% /var/run
none                   4075032         0   4075032   0% /var/lock
none                   4075032         0   4075032   0% /lib/init/rw
isengard.mines.edu:/usr/local/cwp
                      20314752   6037440  13228736  32% /usr/local/cwp
isengard.mines.edu:/usr/local/sedpak54
                      20314752   6037440  13228736  32% /usr/local/sedpak54
isengard.mines.edu:/u
                     206424768  50614912 145324096  26% /u
isengard.mines.edu:/data/cwpscratch
                      30963712   9732128  19658720  34% /cwpscratch
isengard.mines.edu:/data
                     103212320  19418464  78550976  20% /data
```

```
isengard.mines.edu:/scratch
                    396341312    199520 376008736   1% /scratch
```

the hardware devices on the far left column. Those whose names begin with "dev" are hardware **devices** on the specific computer. The items that begin with a machine name, in this case "isengard.mines.edu" exist physically on another machine (named "isengard"), but are **remotely mounted** as to appear to be on this machine. The second column from the left shows the total space on the device, the third column shows the amount of space used, while the fourth shows the amount available, the fifth column shows the usage as a percentage of space used. Finally the far right column shows the directory where these devices are mounted.

In Unix devices are mounted in such a way that they appear to be files or directories. Under Unix-like operating systems, the user sees only a directory tree, and not individual hardware devices.

If you try editing files in some of these other directories you will find that you likely do not have permission to read, write, or modify the contents of many those directories. Unix is a multi-user environment, meaning that from an early day, the notion of protecting users from each other and from themselves, as well as protecting the operating system from the users has been a priority from day one.

In none of these examples have we used a browser, yet there are browsers available on most Unix systems. There is no fundamental problem with using a browser, with the exception that you have to take your hands off the keyboard to use the mouse. The browser will not tell you where you are located within a terminal window. If you must use a browser, use "column view" rather than "icon view" as we will have many levels of nested directories to navigate.

## 1.9 Scratch and Data directories

Directories with names such "scratch" and "data" are often provided with user write permission so that users may keep temporary files and data files out of their home directories. Like "scratch paper" a scratch directory is usually for temporary file storage, and is not backed up. Indeed, on any computer system there may be "scratch" directories that are not called by that name.

Also, such directories may be physically located on the specific machine were you are seated and may not be visible on other machines. Because the redundancy of backups require extra storage, most system administrators restrict the amount of backed up space to a relatively small area of a computer system. To restrict user access, quotas may be imposed that will prevent users from using so much space that a single user could fill up a disk. However, in scratch areas there usually are no such restriction, so it is preferable to work in these directories, and save only really important materials in your home directory.

Users should be aware, that administration of scratch directories may not be user friendly. Using up all of the space on a partition may have dire consequences, in that the

administrator may simply remove items that are too big, or have a policy of removing items that have not been accessed over a certain period of time. A system administrator may also set up an automated "grim file reaper" to automatically delete materials that have not been accessed after a period of time. **Because files are not always automatically backed up, and because hardware failures are possible on any system, it is a good idea for the user to purchase USB storage media and get in the habit of making personal backups on a regular basis.** A less hostile mode of management is to institute **quotas** to prevent single users from hogging the available scratch space.

You may see a scratch directory on any of the machines in your lab, but these are different directories, each located on a different hard drive. This can lead to confusion as a user may copy stuff into a scratch area on one day, and then work on a different computer on a different day, thinking that their stuff has been removed.

The availability and use of scratch directories is important, because each user has a quota that limits the amount of space that he or she may use in his/her home directory.

On systems where a scratch directory is provided, that also has write permission, the user may create his/her personal work area via

```
$ cd /scratch
$ mkdir yourusername                    <--- here "yourusername" is the
                                             your user name on the system
```

Unless otherwise stated, this text will assume that you are conducting further operations in your personal scratch work area.

## 1.10 Shell environment variables and path

The working shell is a program that has a configuration that gives the user access to executable files on the system. Recall that echoing the value of the SHELL variable

```
$ echo $SHELL                           <--- returns the value of the users'
                                             working shell environment
```

tells you what shell program is your working shell environment. There are other environmental variables other than SHELL. Again, note that if this command returns one of the values

```
/bin/sh
/bin/ksh
/bin/bash
/bin/zsh
```

then you are working in the SH-family and need to follow instructions for working with that type of environment. If, on the other hand, the **echo $SHELL** command returns one of the values

```
/bin/csh
/bin/tcsh
```

then you are working in the CSH-family and need to follow the alternate series of instructions given.

In the modern world of Linux, it is quite common for the default shell to be something called binbash an open-source version of binsh.

### 1.10.1 The path or PATH

Another important variable is the "path" or "PATH". The value path variable tells the location that the working shell looks for executable files in. Usually, executables are stored in a sub directory "bin" of some directory. Because there may be many software packages installed on a system, there may be many such locations.

To find out what paths you can access, which is to say, which executables your shell can see, type

```
$ echo $path
```

or

```
$ echo $PATH
```

The result will be a listing, separated by colons ":" of paths or by spaces " " to executable programs.

### 1.10.2 The CWPROOT variable

The variable PATH is important, but SHELL and PATH are not the only possible environment variable. Often programmers will use an environment variable to give a users' shell access to some attribute or information regarding a specific piece of software. This is done because sometimes software packages are of restricted interest.

For SU the path CWPROOT is necessary for running the SU suite of programs. We need to set this environment variable, and to put the suite of Seismic Unix programs on the users' path.

## 1.11 Shell configuration files

Because the users' shell has as an attribute a natural programming language, many configurations of the shell environment are possible. To find the configuration files for your operating system, type

```
$ ls -a                                  <--- show directory listing of all
                                              files and sub directories
$ pwd                                    <--- print working directory
```

then the user will see a number of files whose names begin with a dot ".".

## 1.12 Setting up the working environment

One of the most difficult and confusing aspects of working on Unix-like systems is encountered right at the beginning. This is the problem of setting up user's personal environment. There are two sets of instructions given here. One for the CSH-family of shells and the other for the SH-family.

### 1.12.1 The CSH-family

Each of the shell types returned by $SHELL has a different configuration file. For the csh-family (tcsh,csh), the configuration files are ".cshrc" and ".login". To configure the shell, edit the file .cshrc. Also, the "path" variable is *lower case*.

You will likely find a line beginning with

```
set path=(
```

with entries something like

```
set path=( /lib ~/bin /usr/bin/X11 /usr/local/bin /bin
                              /usr/bin  . /usr/local/bin /usr/sbin )
```

Suppose that the Seismic Unix package is installed in the directory

```
/usr/local/cwp
```

on your system.

Then we would add one line above to set the "CWPROOT" environment variable. And one line below to define the user's "path"

```
setenv CWPROOT /usr/local/cwp

set path=( /lib ~/bin /usr/bin/X11 /usr/local/bin /bin
                              /usr/bin  . /usr/local/bin /usr/sbin )

set path=( $path $CWPROOT/bin )
```

Save the file, and log out and log back in. You will need to log out completely from the system, not just from particular terminal windows.

When you log back in, and pull up a terminal window, typing

```
$ echo $CWPROOT
```

will yield

```
/usr/local/cwp
```

and

```
$ echo $PATH
```

will yield

```
/lib /u/yourusername/bin /usr/bin/X11 /usr/local/bin /bin
                        /usr/bin . /usr/local/bin /usr/sbin /usr/local/cwp/bin
```

### 1.12.2 The SH-family

The process is similar for the SH-family of shells. The file of interest has a name of the form ".profile," .bashrc," and the ".bash_profile." The ".bash_profile" is read once by the shell, but the ".bashrc" file is read everytime a window is opened or a shell is invoked. Thus, what is set here influences the users complete environment. The default form of this file may show a path line similar to

```
PATH=$PATH:$HOME/bin:.:/usr/local/bin
```

which should be edited to read

```
export CWPROOT=/usr/local/cwp
PATH=$PATH:$HOME/bin:.:/usr/local/bin:$CWPROOT/bin
```

The important part of the path is to add the

```
:$CWPROOT/bin
```

on the end of the PATH line, no matter what it says.

The user then logs out and logs back in for the changes to take effect. In each case, the PATH and CWPROOT variables are necessary to be set for the users' working shell environment to find the executables of Seismic Unix.

## 1.13 Unix help mechanism- Unix man pages

Every program on a Unix or Unix-like system has a system manual page, called a **man page**, that gives a terse description of its usage. For example, type:

```
$ man ls
$ man cd
$ man df
$ man sh
$ man bash
$ man csh
```

to see what the system says about these commands. For example:

```
$ man ls

LS(1)                          User Commands                          LS(1)



NAME
       ls - list directory contents

SYNOPSIS
       ls [OPTION]... [FILE]...

DESCRIPTION
       List  information  about  the FILEs (the current directory by default).
       Sort entries alphabetically if none of -cftuvSUX nor --sort.

       Mandatory arguments to long options are  mandatory  for  short  options
       too.

       -a, --all
              do not ignore entries starting with .

       -A, --almost-all
              do not list implied . and ..
--MORE-
```

The item at the bottom that says –**MORE**– indicates that the page continues. To see the rest of the man page for **ls** is viewed by hitting the space bar. View the Unix man page for each of the Unix commands you have used so far.

Most Unix commands have options such as the **ls -a** which allowed you to see files beginning with dot "." or **ls -l** which shows the "long listing" of programs. Remember to view the Unix man pages of each new Unix command as it is presented.

# Chapter 2

# Lab Activity #1 - Getting started with Unix and SU

Any program that has executable permissions and which appears on the users' PATH may be run by simply typing its name on the commandline. For example, if you have set your path correctly, you should be able to do the following

```
$ suplane | suxwigb  &
                     ^ this symbol, the ampersand, indicates that
                       the program is being run in background
          ^ the "pipe" symbol
```

The commandline itself is the interactive prompt that the shell program is providing so that you can supply input. The proper input for a commandline is an executable file, which may be a compiled program or a Unix shell script. The command prompt is saying, "Type program name here."

Try running this command with and without the ampersand &. If you run

```
$ suplane | suxwigb
```

The plot comes up, but you have to kill the plot window before you can get your commandline back, whereas

```
$ suplane | suxwigb  &
```

allows you to have the plot on the screen, and have the commandline.

To make the plot better we may add some axis labeling:

```
$ suplane | suxwigb title="suplane test pattern"
                            label1="time (s)" label2="trace number" &

                            ^ Here the command is broken across a line
                              so it will fit this page of this book.
                              On your screen it would be typed as one
                              long line.
```

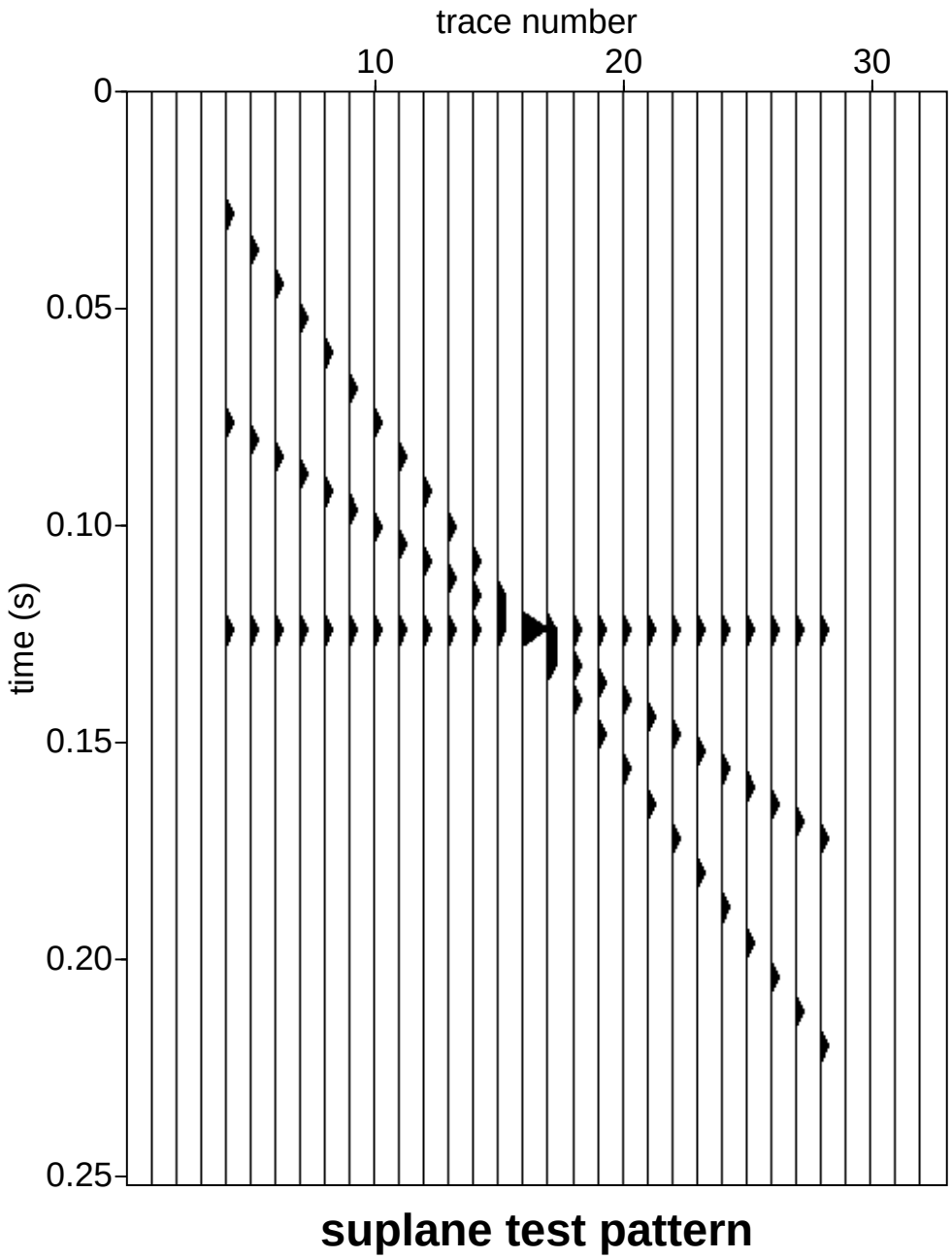



Figure 2.1: The **suplane test pattern.**

to see a test pattern consisting of three intersecting lines in the form of seismic traces. The data consist of seismic traces with only single values that are nonzero. This is *variable area* display in which each place where the trace is positive valued is shaded black. See Figure 2.1.

Equivalently, you should see the same output by typing

```
$ suplane > junk.su
$ suxwigb < junk.su  title="suplane test pattern"
                                label1="time (s)" label2="trace number" &
```

Finally, we often need to have graphical output that can be imported into documents. In SU we have graphics programs that write output in the PostScript language

```
$ supswigb < junk.su title="suplane test pattern"
                       label1="time (s)" label2="trace number" > suplane.eps
```

## 2.1 Pipe |, redirect in < , redirect out >, and run in background &

In the commands in the last section we used three symbols that allow files and programs to send data to each other and to send data between programs. The vertical bar | is called a "pipe" on all Unix-like systems. Output sent to standard out may be piped from one program to another program as was done in the example of

```
$ suplane | suxwigb  &
```

which, in English may be translated as "run **suplane** (pipe output to the program) **suxwigb** where the & says (run all commands on this line in background)." The pipe | is a memory buffer with a "read from standard input" for an input and a "write to standard output" for an output. You can think of this as a kind of plumbing. A stream of data, much like a stream of water is flowing from the program **suplane** to the program **suxwigb**.

The "greater than" sign > is called "redirect out" and

```
$ suplane > junk.su
```

says "run **suplane** (writing output to the file) junk.su. The > is a buffer which reads from standard input and writes to the file whose name is supplied to the right of the symbol. Think of this as data pouring out of the program **suplane** into the file junk.su.

The "lest than" sign < is called "redirect in" and

```
$ suxwigb < junk.su   &
```

says "run **suxwigb** (reading the input from the file ) junk.su (run in background).

- | = pipe from program to program

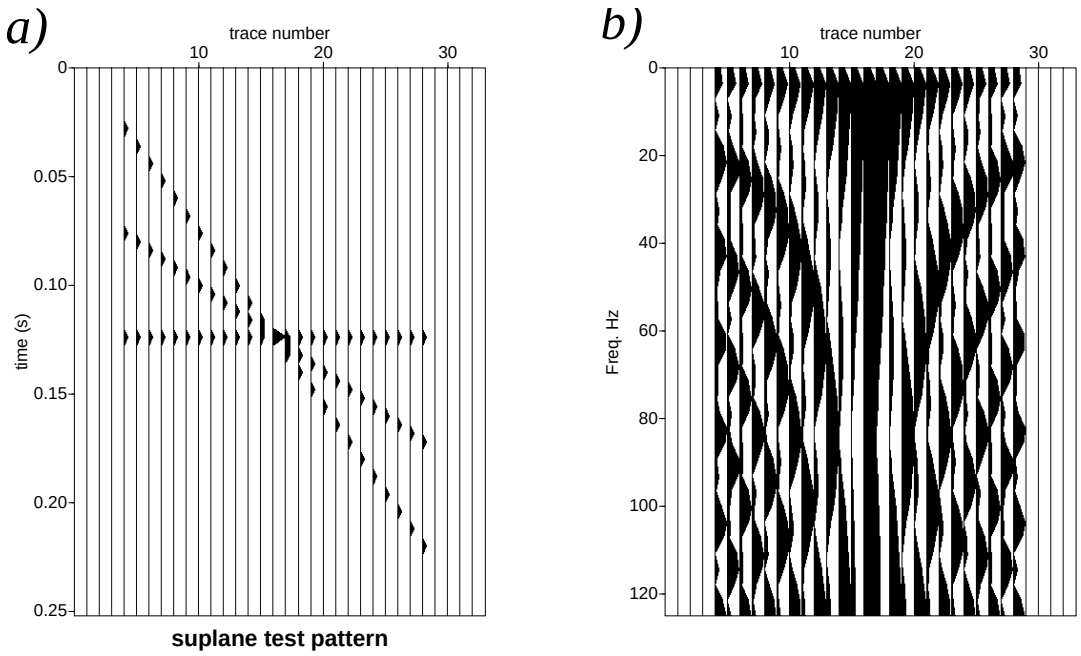



Figure 2.2: a) The **suplane** test pattern. b) the Fourier transform (time to frequency) of the **suplane** test pattern via **suspecfx**.

- > = write data from program to file (redirect out)
- < = read data from file to program (redirect in)
- & = run program in background

## 2.2 Stringing commands together

We may string together programs via pipes (|), and input and output via redirects (>) and (<). An example is to use the program suspecfx to look at the amplitude spectrum of the traces in data made with suplane:

```
$ suplane | suspecfx | suxwigb   &          --make suplane data, find
                                          the amplitude spectrum,
                                          plot as wiggle traces
```

Equivalently, we may do

```
$ suplane > junk.su                  --make suplane data, write to a file.
$ suspecfx < junk.su > junk1.su      --find the amplitude spectrum, write to
                                     a file.
$ suxwigb < junk1.su   &              -- view the output as wiggle traces.
```

This does exactly the same thing, in terms of final output as the previous example, with the exception that here, two files have been created. See Figure 2.2.

### 2.2.1 Questions for discussion

- What is the Fourier transform of a function?
- What is an amplitude spectrum?
- Why do the plots of the amplitude spectrum in Figure 2.2 appear as they do?

## 2.3 Unix Quick Reference Cards

The two figures, Fig 2.3 and Fig 2.4 are a Quick Reference cards for some Unix commands

Figure 2.3: UNIX Quick Reference card p1. From the University References

## Working with NFS files

Files saved on the UITS central Unix computers Chrome, Cobalt, Zinc, Steel, EZinfo, and STARRS/SP are stored on the Network File Server (NFS). That means that your files are really on one disk, in directories named for the central Unix hosts on which you have accounts.

No matter which of these computers you are logged into, you can get to your files on any of the others. Here are the commands to use to get to any system directory from any other system:

cd /N/u/*username*/Chrome/
cd /N/u/*username*/Cobalt/
cd /N/u/*username*/Zinc/
cd /N/u/*username*/Steel/
cd /N/u/*username*/Ezinfo/
cd /n/u/*username*/SP/

Be sure you use the capitalization just as you see above, and substitute your own username for *username*.

For example, if Jessica Rabbit is logged into her account on Steel, and wants to get a file on her EZinfo account, she would enter:

**cd /N/u/jrabbit/Ezinfo/**

Now when she lists her files, she'll see her EZinfo files, even though she's actually logged into Steel.

You can use the ordinary Unix commands to move files, copy files, or make symbolic links between files. For example, if John Doe wanted to move "file1" from his Steel directory to his EZinfo directory, he would enter:

**mv -i /N/u/jdoe/Steel/file1 /N/u/jdoe/Ezinfo/**

This shared file system means that you can access, for example, your Chrome files even when you are logged into Cobalt, and vice versa. However, if you are logged into Chrome, you can only use the software installed on Chrome —only users' directories are linked together, not system directories.

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# Unix commands reference card

***Abbreviations used in this pamphlet***

| | |
|---|---|
| **Ctrl/x** | hold down control key and press x |
| **d** | directory |
| **env** | environment |
| **f** | filename |
| **n** | number |
| **nd** | computer node |
| **var** | variable |
| **[y/n]** | yes or no |
| [] | optional arg |
| **...** | list |

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World Wide Web, set your browser to
*http//www.indiana.edu/~uitspubs/b017/*

## Environment Control

| Command | Description |
|---|---|
| cd *d* | *Change to directory d* |
| mkdir *d* | *Create new directory d* |
| rmdir *d* | *Remove directory d* |
| mv *f1 [f2...] d* | *Move file f to directory d* |
| mv *d1 d2* | *Rename directory d1 as d2* |
| passwd | *Change password* |
| alias *name1 name2* | *Create command alias* |
| unalias *name1* | *Remove command alias name1* |
| rlogin *nd* | *Login to remote node* |
| logout | *End terminal session* |
| setenv *name v* | *Set env var to value v* |
| unsetenv *name1 name2...]* | *remove environment variable* |

## Output, Communication, & Help

| Command | Description |
|---|---|
| lpr -P *printer f* | *Output file f to line printer* |
| script *[f]* | *Save terminal session to f* |
| exit | *Stop saving terminal* |
| *session* | |
| mail *username* | *Send mail to user* |
| biff *[y/n]* | *Instant notification of mail* |
| man *name* | *UNIX manual entry for* |
| *name* | |
| learn | *Online tutorial* |

## Process Control

| Command | Description |
|---|---|
| Ctrl/c * | *Interrupt processes* |
| Ctrl/s * | *Stop screen scrolling* |
| Ctrl/q * | *Resume screen output* |
| sleep *n* | *Sleep for n seconds* |
| jobs | *Print list of jobs* |
| kill [%n] | *Kill job n* |
| ps | *Print process status stats* |
| kill -9 *n* | *Remove process n* |
| Ctrl/z * | *Suspend current process* |
| stop *%n* | *Suspend background job n* |
| *command&* | *Run command in background* |
| bg [*%n*] | *Resume background job n* |
| fg [*%n*] | *Resume foreground job n* |
| exit | *Exit from shell* |

## Environment Status

| Command | Description |
|---|---|
| ls *[d] [f...]* | *List files in directory* |
| ls *-1 [f...]* | *List files in detail* |
| alias *[name]* | *Display command aliases* |
| printenv *[name]* | *Print environment values* |
| quota | *Display disk quota* |
| date | *Print date & time* |
| who | *List logged in users* |
| whoami | *Display current user* |
| finger *[username]* | *Output user information* |
| chfn | *Change finger information* |
| pwd | *Print working directory* |
| history | *Display recent commands* |
| *! n* | *Submit recent command n* |

## File Manipulation

| Command | Description |
|---|---|
| *vi [f]* | *Vi fullscreen editor* |
| emacs *[f]* | *Emacs fullscreen editor* |
| ed *[f]* | *Text editor* |
| wc *f* | *Line, word, & char count* |
| cat *f* | *List contents of file* |
| more *f* | *List file contents by screen* |
| cat *f1 f2 > f3* | *Concatenates f1 & f2 into f3* |
| chmod *mode f* | *Change protection mode of f* |
| cmp *f1 f2* | *Compare two files* |
| cp *f1 f2* | *Copy file f1 into f2* |
| sort *f* | *Alphabetically sort f* |
| split *[-n] f* | *Split f into n-line pieces* |
| mv *f1 f2* | *Rename file f1 as f2* |
| rm *f* | *Delete (remove) file f* |
| grep *'ptn' f* | *Outputs lines that match ptn* |
| diff *f1 f2* | *Lists file differences* |
| head *f* | *Output beginning of f* |
| tail *f* | *Output end of f* |

## Compiler

| Command | Description |
|---|---|
| cc *[-o f1] f2* | *C compiler* |
| lint *f* | *Check C code for errors* |
| f77 *[-o f1] f2* | *Fortran77 compiler* |
| pc *[-o f1] f2* | *Pascal compiler* |

Press RETURN at the end of each command, except those marked by an asterisk (*).

Figure 2.4: UNIX Quick Reference card p2.

# Chapter 3

# Lab Activity #2 - viewing data

Just as scratch paper is paper that you use temporarily without the plan of saving for the long term, a "scratch directory" is temporary working space, which is not backed up and which may be arbitrarily cleared by the system administrator. Each computer in this lab has a directory called **/scratch** that is provided as a temporary workspace for users. It is in this location that you will be working with data. Create your own **scratch** directory via:

```
$ mkdir /scratch/yourusername
```

Here "yourusername" is the actual username that you are designated as on this system. Please feel free to ask for help as you need it.

The **/scratch** directory may reside physically on the computer where you are sitting, or it may be remotely mounted. In computer environements where the directory is locally on the a given computer, you will have to keep working on the same system. If you change computers, you will have to transfer the items from your personal scratch area to that new machine. In labs where the directory is remotely mounted, you may work on any machine that has the directory mounted.

Remember: **/scratch** directories are **not backed up**. If you want to save materials permanently, it is a good idea to make use of a USB storage device.

### 3.0.1 Data image examples

Three small datasets are provided. These are labeled "sonar.su," "radar.su," and "seismic.su" and are located in the directory

```
/cwpscratch/Data1/
```

We will pretend that these data examples are "data images," which is to say these are examples that require no further processing.

Do the following:

```
$ cd /scratch/yourusername     (this takes you to /scratch/yourusername)
```

```
^
This "$" represents the prompt at the beginning of the commandline.
Do not type the "$" when entering commands.


$ mkdir  Temp1               (this creates the directory Temp1)
$ cd  Temp1                  (change working directory to Temp1)
$ cp /cwpscratch/Data1/sonar.su  .
$ cp /cwpscratch/Data1/radar.su  .
$ cp /cwpscratch/Data1/seismic.su  .
                                ^  This is a literal dot ".", which
                                      means "the current directory"
$ ls              ( should show  the file sonar.su )
```

For the rest of this document, when you are directed to make "Temp" directories, it will be assumed that you are putting these in your personal scratch directory.

## 3.1 Viewing an SU data file: Wiggle traces and Image plots

Though we are assuming that the examples **sonar.su**, **seismic.su**, and **radar.su** are finished products, our mode of presentation of these datasets may change the way we view them entirely. Proper presentation can enhance features we want to see, suppress parts of the data that we are less interested in, accentuate signal and suppress noise. Improper presentation, on the other hand, can take turn the best images into something that is totally useless.

### 3.1.1 Wiggle traces

A common mode of presentation of seismic data is the "wiggle trace." Such a representation consists of representing the oscillations of the data as a graph of amplitude as a function of time, with successive traces plotted side-by-side. Amplitudes of one polarity (usually positive) are shaded black, where as negative amplitudes are not shaded. Note that such presentation introduces a bias in the way we view the data, accentuating the positive amplitudes. Furthermore, wiggle traces may make dipping structures appear fatter than they actually are owing to the fact that a trace is a vertical slice through the data.

In SU we may view a wiggle trace display of data via the program **suxwigb**. For example, viewing the **sonar.su** data as wiggle traces is done by "redirecting in" the data file into "suxwigb"

```
$ suxwigb < sonar.su      &
                          ^ the ampersand (&) means "run in background"
```

This should look horrible! The problem is that there are 584 wiggle traces, side by side. Place the cursor on the plot and drag, while holding down the index finger mouse button. This is called a "rubberband box." Try grabbing a strip of the data of width less than 100 traces, by placing the cursor at the top line of the plot, and holding the index finger mouse button while dragging to the lower right. Zooming in this fashion will show wiggles. The less on here is that you need a relatively low density of data on your print medium for wiggle traces.

Place the mouse cursor on the plot, and type "q" to kill the window.

Try the **seismic.su** and the **radar.su** data as wiggle traces via

```
$ suxwigb < seismic.su      &
$ suxwigb < radar.su      &
```

In each case, zoom in on the data until you are able to see the oscillations of the data.

### 3.1.2 Image plots

The seismic data may be thought of as an array of floating point numerical values, each representing a seismic amplitude at a specific $(t, x)$ location. A plot consisting of an array of gray or color dots, with each gray level or color representing the respective value is called an "image" plot.

If we view An alternative is an image plot:

```
$ suximage < sonar.su      &
```

This should look better. We usually use image plots for datasets of more than 50 traces. We use wiggle traces for smaller datasets.

## 3.2 Greyscale

There are only 256 shades of gray available in this plot. If a single point in the dataset makes a large spike, then it is possible that most of the 256 shades are used up by that one amplitude. Therefore scaling amplitudes is often necessary. The simplest processing of the data is to amplitude truncate ("clip") the data. (The term "clip" refers to old time strip chart records, which when amplitudes were too large appeared if someone had taken scissors and clipped of the tops of the sinusoids of the oscillations.) Try:

```
$ suximage < sonar.su  perc=99     &
$ suximage < sonar.su perc=99 legend=1
```

The perc=99 passes only those items of the 99th percentile and below in amplitude. (You may need to look up "percentile" on the Internet.) In other words, it "clips" (amplitude truncates) the data to remove the top 1 per cent of amplitudes. Try different values of "perc" to see what this does.

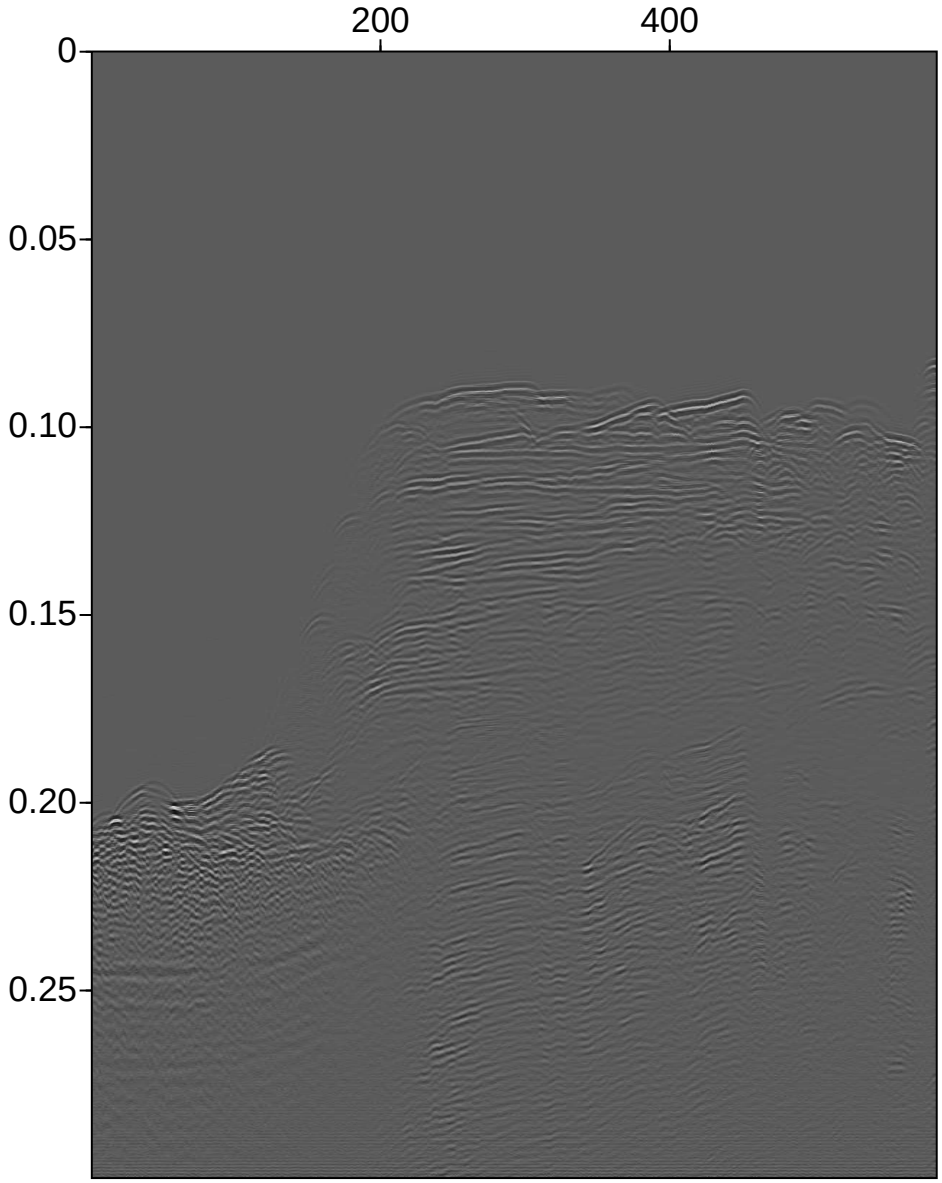


Figure 3.1: Image of **sonar.su** data (no perc). Only the largest amplitudes are visible.

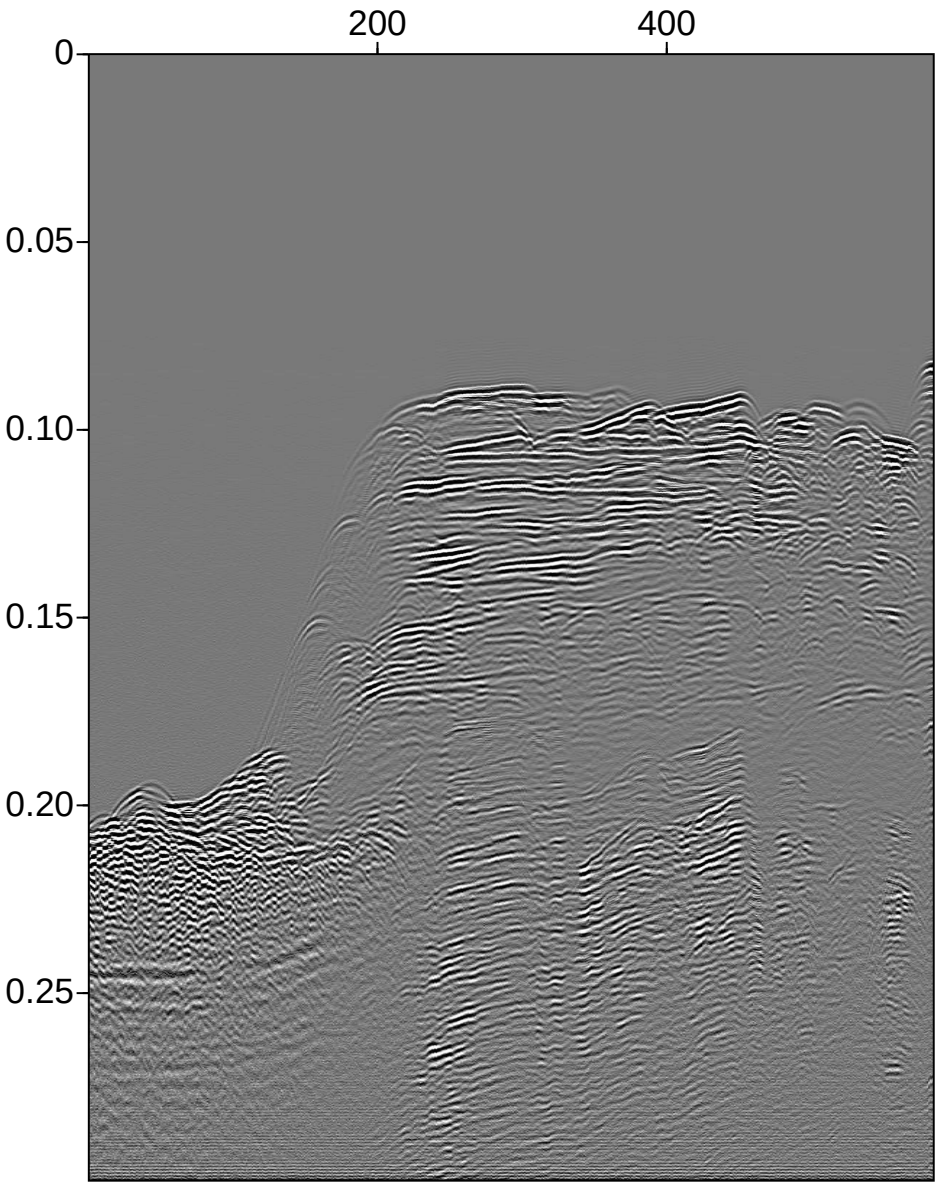


Figure 3.2: Image of **sonar.su** data with perc=99. Clipping the top 1 percentile of amplitudes brings up the lower amplitude amplitudes of the plot.

## 3.3 Legend ; making grayscale values scientifically meaningful

To be scientifically useful, which is to say "quantitative" we need to be able to translate shades of gray into numerical values. This is done via a gray scale, or "legend". A "legend" is a scale or other device that allows us to see the meanings of the graphical convention used on a plot. Try:

```
$ suximage < sonar.su  legend=1     &
```

This will show a grayscale bar.

There are a number of colorscales available. Place the mouse cursor on the plot and press "h" you will see that further pressings of "h" will re plot the data in a different colorscale. Now press "r" a few times. The "h" scales are scales in "hue" and the "r" scales are in red-green-blue (rgb). Note that the brightest part of each scale is chosen to emphasize a different amplitude.

With colormapping some parts of the plot may be emphasized at the expense of other parts. The issue of colormaps often is one of selecting the location of the "bright part" of the colorbar, versus darker colors. Even perfectly processed data may be rendered uninterpretable by a poor selection of colormapping. This effect may be seen in Figure 3.4.

Repeat the previous, this time clipping by percentile

```
$ suximage < sonar.su  legend=1  perc=99    &
```

The ease at which colorscales are defined, and the fact that there are no real standards on colorscales, mean that effectively every color plot you encounter requires a colorscale for you to be able to know what the values mean. Furthermore, some colors ranges are brighter than others. By moving the bright color to a different part of the amplitude range, you can totally change the image. This is a source of richness of display, but it is also a potential source of trouble, if the proper balance of color is not chosen.

## 3.4 Normalization: Median balancing

A common data amplitude balancing is to balance the colorscale on the median values in the data. The "median" is the middle value, meaning that half the values are larger than the median value and half the data are less than the median value.

Type these commands to see that in SU:

```
$ sunormalize mode=med < sonar.su | suximage legend=1
$ sunormalize mode=med < sonar.su | suximage legend=1 perc=99
```

We will find **perc=99** to be useful. Note that you may zoom in on regions of the plot you find interesting.

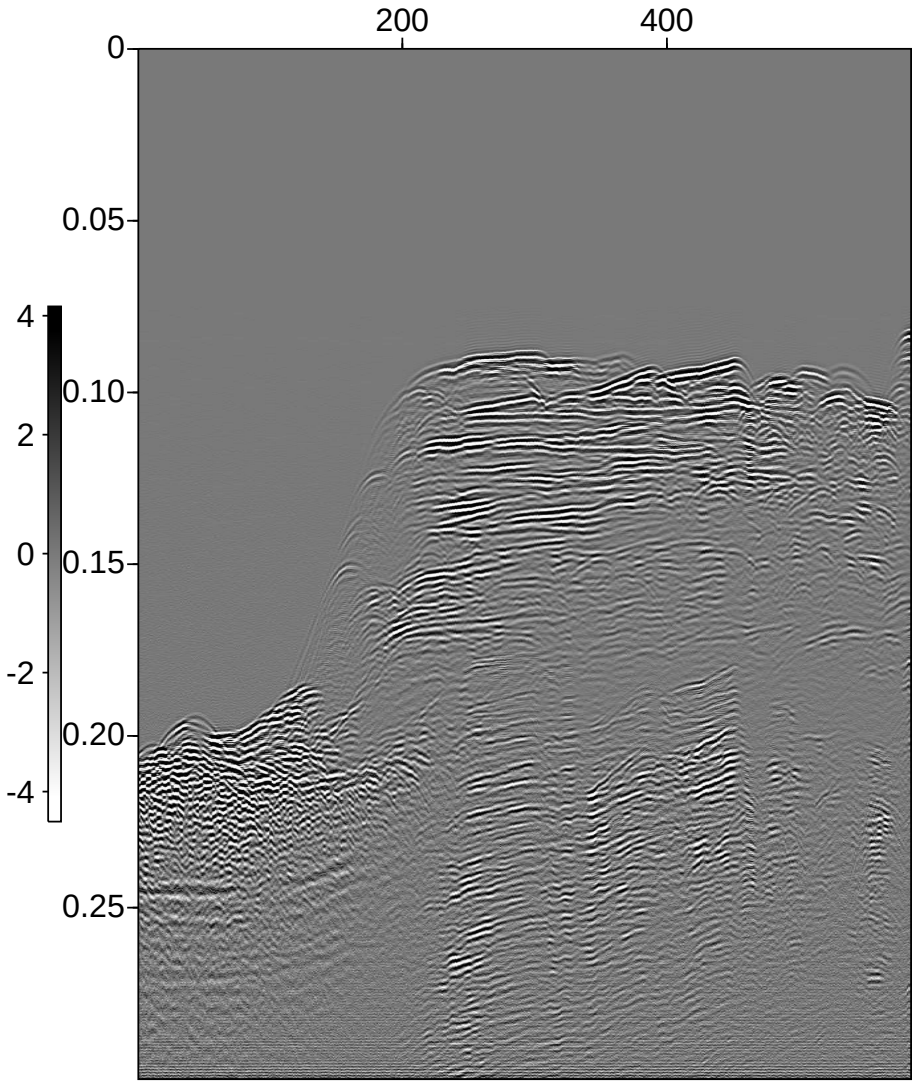


Figure 3.3: Image of **sonar.su** data with perc=99 and legend=1.

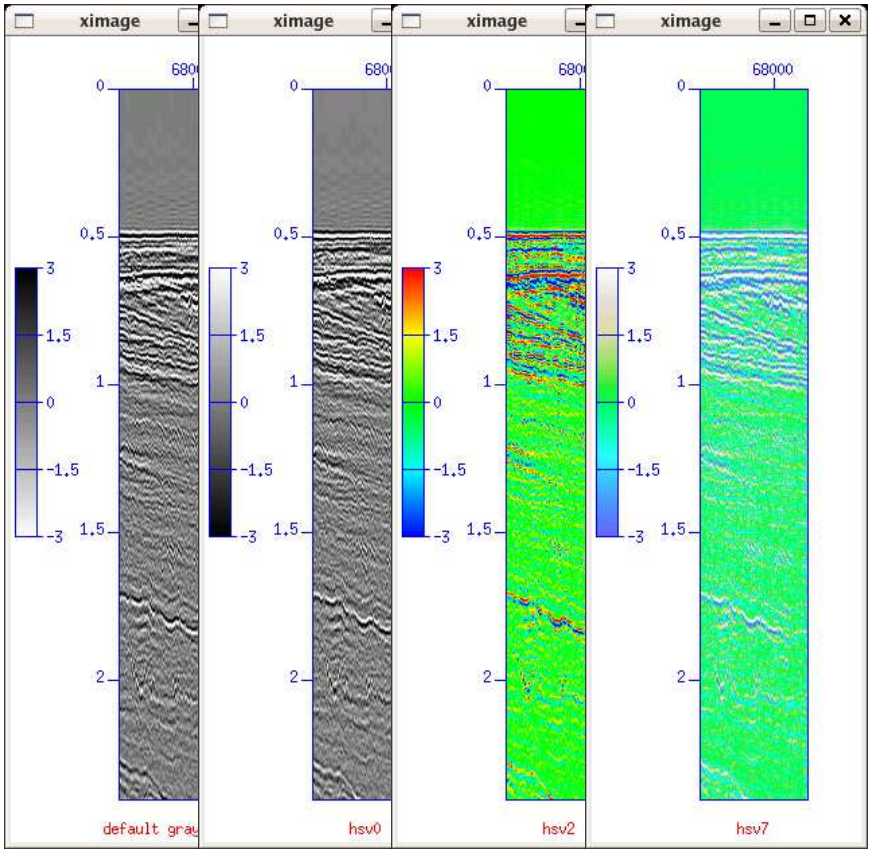


Figure 3.4: Comparison of the default, hsv0, hsv2, and hsv7 colormaps. Rendering these plots in grayscales emphasizes the location of the bright spot in the colorbar.

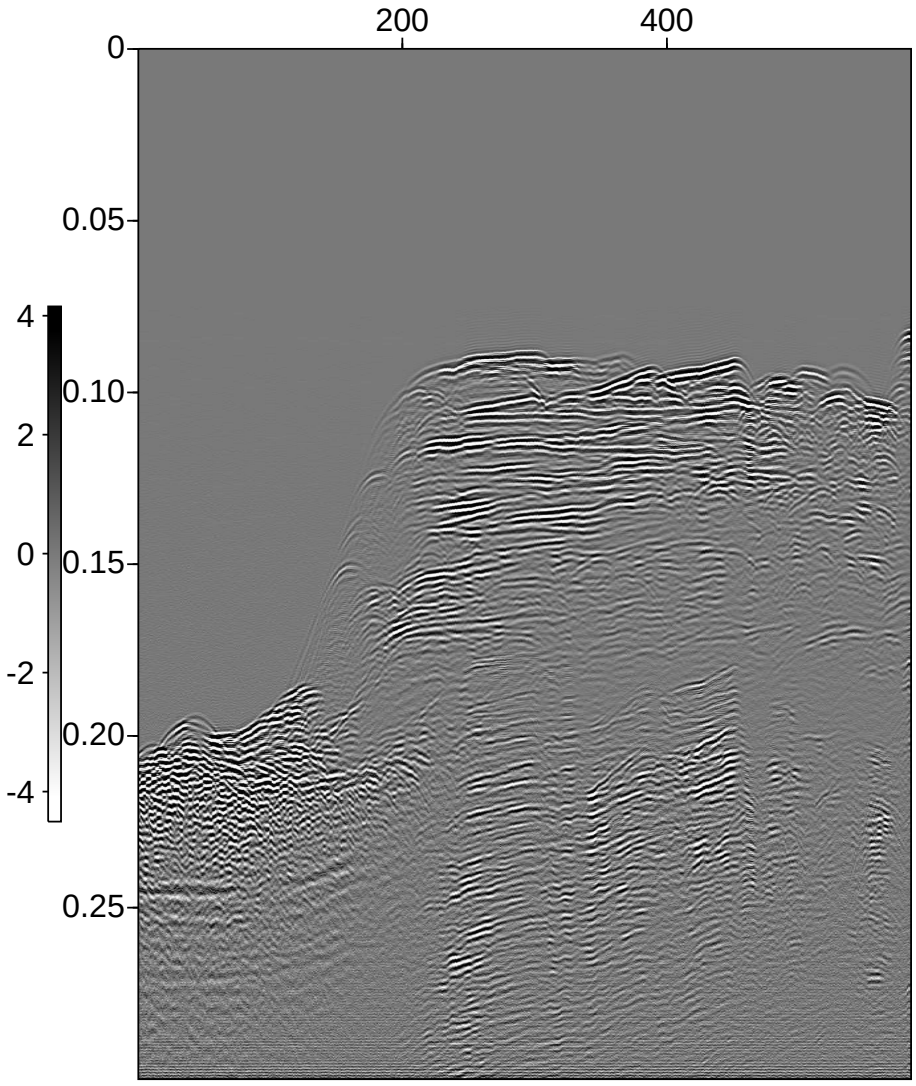


Figure 3.5: Image of **sonar.su** data with perc=99 and legend=1.

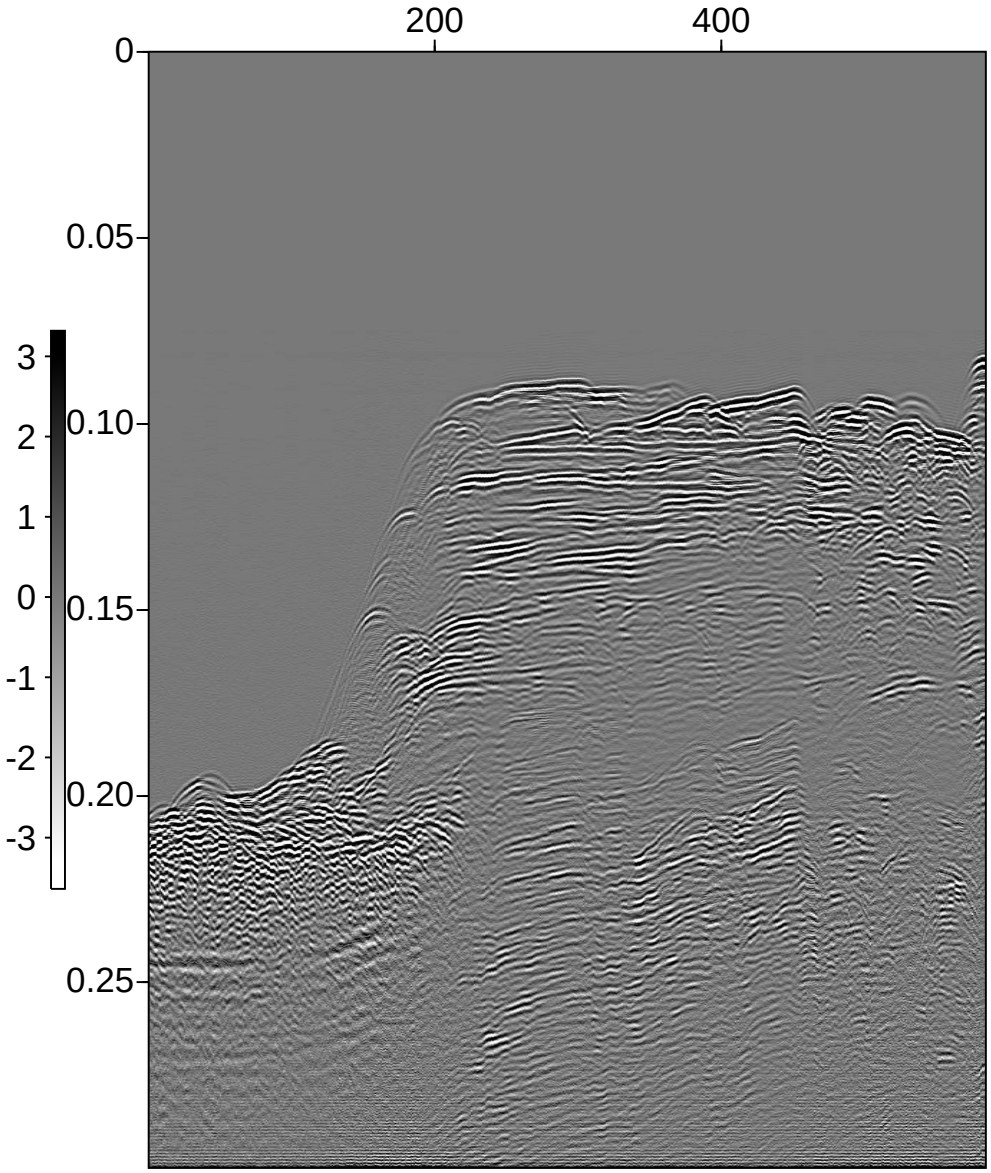


Figure 3.6: Image of **sonar.su** data with median normalization and perc=99

Note, that if you put both the median normalized and simple perc=99 files on the screen side-by-side, there are differences, but these may not be striking differences. The program **suximage** has a feature that the user may change colormaps by pressing the "h" key or the "r" key. Try this and you will see that the selection of the colormap can make a considerable difference in the appearance of the image. Even with the same data, the colormap.

For example in Figure 3.7 we see the result of applying the commands

```
$ suximage < seismic.su wbox=250 hbox=600 cmap=hsv4 clip=3 title="no median" &
```

compared with

```
$ sunormalize mode=median < seismic.su
          | suximage wbox=250 hbox=600 cmap=hsv4 clip=3 title="no median" &
```

Note that the line is broken to fit on the page. When you type this, the pipe | follows immediately after the **seismic.su**. Here, the

## 3.5 Homework problem #1 - Due Thursday 1 Sept 2011

Repeat display gaining experiments of the previous section with "radar.su" and "seismic.su" to see what median balancing, and setting **perc=...** does to these data.

- Capture representative plots with axes properly labeled. You can use the Linux screen capture feature, or find another way to capture plots into a file, (such as by using **supsimage** to make PostScript plots) Feel free to use different values of perc and different colormaps than were used in the previous examples. The OpenOffice Word wordprocessing program is an easy program to use for this.
- Prepare a report of your results. The report should consist of:
  - Your plots
  - a short paragraph describing what you saw. Think of it as a figure caption.
  - a listing of the actual commandlines that you ran to get the plots.
  - Not more than 3 pages total!
  - Make sure that your name, the due date, and the assignment number are at the top of the first page.
- Save your report in the form of a PDF file, and email to john@dix.mines.edu

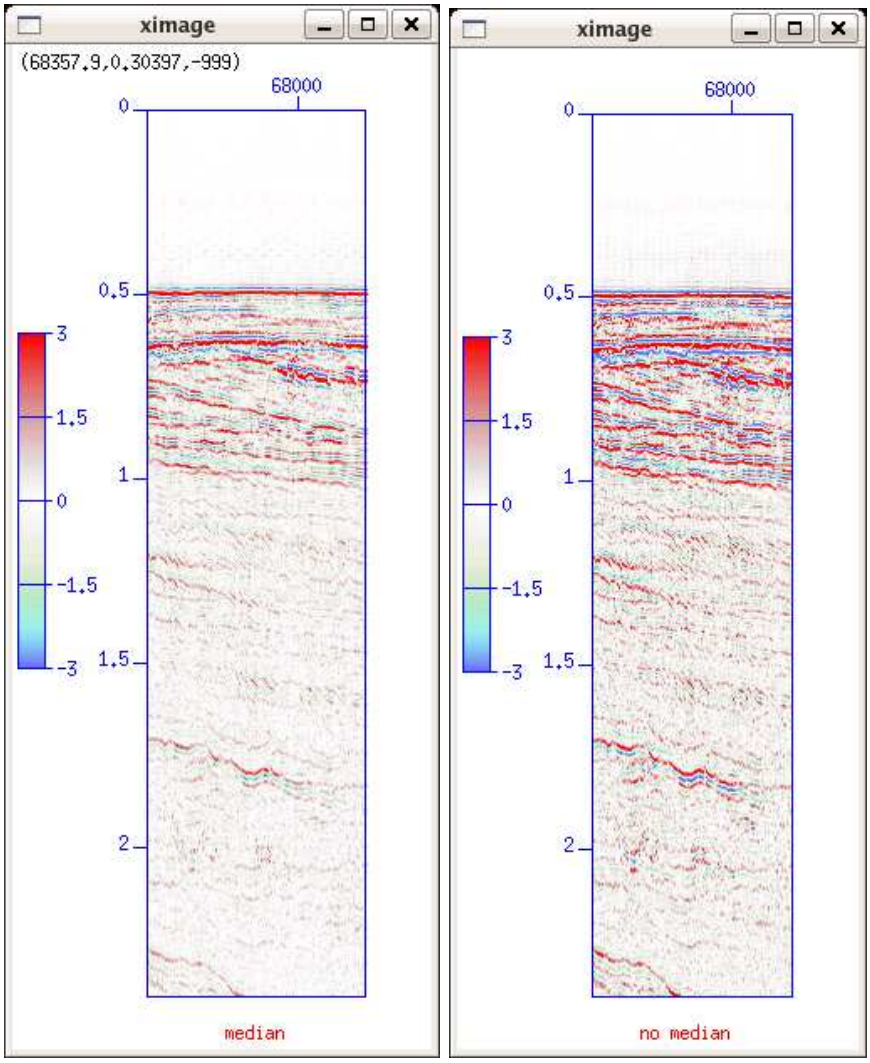


Figure 3.7: Comparison of **seismic.su** median-normalized, with the same data with no median normalization. Amplitudes are clipped to 3.0 in each case. Note that there are features visible on the plot without median normalization that cannot be seen on the median normalized data.

## 3.6 Concluding Remarks

There are many ways of presenting data. Two of the most important questions that a scientist can ask when seeing a plot are "What is the meaning of the colorscale or grayscale of a plot?" and "What normalization or balancing has been applied to the data before the plot?" The answers to these questions may be as important as the answer to the question "What processing has been applied to these data?"

### 3.6.1 What do the numbers mean?

The scale divisions seen on the plots in this chapter that have been obtained by running **suximage** with **legend=1** show numerical values, values that are changed when we apply display gain. Ultimately, these numbers relate to the voltage recorded from a transducer (a geophone, hydrophone, or accelerometer). While in theory we should be able to extract information about the size of the ground displacement in, say *micrometers*, or the pressure field strength in, say *megapascals* there is little reason to do this. Owing to detector and source coupling issues, and the fact that data must be gathered quickly, we really are only interested in relative values.

# Chapter 4

# Help features in Seismic Unix

Scientific processing and data manipulation packages usually contain many commands. Seismic Unix is no exception. As with any package there are help features to help you navigate the collection of programs and modules. The first thing that you must do with any software package is to locate and learn to use the help features in the package. Usually these help mechanisms are not very "helpful" to the beginner, but are really more like quick reference guides for people who are already familiar with the package.

There are a number of help features in SU; here we will discuss only three.

## 4.1 The selfdoc

All Seismic Unix programs have the feature that if the name of the program is typed with no arguments, a self-documentation feature called a **selfdoc** is listed.

Try:

```
$ suplane
$ suximage
$ suxwigb
$ sunormalize
```

For example:

```
$ suplane
```

yields

```
SUPLANE - create common offset data file with up to 3 planes

suplane [optional parameters] >stdout

Optional Parameters:
 npl=3                   number of planes
 nt=64          number of time samples
```

```
 ntr=32          number of traces
 taper=0                 no end-of-plane taper
                         = 1 taper planes to zero at the end
 offset=400              offset
 dt=0.004                time sample interval in seconds
...plane 1 ...
        dip1=0           dip of plane #1 (ms/trace)
        len1= 3*ntr/4    HORIZONTAL extent of plane (traces)
        ct1= nt/2        time sample for center pivot
        cx1= ntr/2       trace for center pivot
...plane 2 ...
        dip2=4           dip of plane #2 (ms/trace)
        len2= 3*ntr/4    HORIZONTAL extent of plane (traces)
        ct2= nt/2        time sample for center pivot
        cx2= ntr/2       trace for center pivot
--More--
```

As with the Unix man pages, typing the space bar shows the rest of the help page.

Each of these programs has a relatively large number of possible argument settings. The programs "suxwigb" and "suximage" both call programs named, respectively, "xwigb" and "ximage". Type:

```
$ ximage
$ xwigb
```

All of the setting for "xwigb" and "ximage" apply to "suxwigb" and "suximage." That is a lot of settings.

Correspondingly, there are plotting programs that write out PostScript graphics output for plotting

```
$ supsimage
$ psimage
$ supswigb
$ pswigb
$ supswigp
$ pswigp
```

The "SU" versions of these programs call the respective programs that do not have the "su" prefix.

## 4.2 Finding the names of programs with: suname

SU is big package containing several hundred programs as well as hundreds of library functions, shell scripts, and associated files. Occasionally we would like to see the total scope of the package we are working with.

For an inventory of the SU programs, typing

```
$ suname
```

yields

```
 -----  CWP Free Programs -----
CWPROOT=/usr/local/cwp

Mains:

In CWPROOT/src/cwp/main:
* CTRLSTRIP - Strip non-graphic characters
* DOWNFORT - change Fortran programs to lower case, preserving strings
* FCAT - fast cat with 1 read per file
* ISATTY - pass on return from isatty(2)
* MAXINTS - Compute maximum and minimum sizes for integer types
* PAUSE - prompt and wait for user signal to continue
* T - time and date for non-military types
* UPFORT - change Fortran programs to upper case, preserving strings

In CWPROOT/src/par/main:
A2B - convert ascii floats to binary
B2A - convert binary floats to ascii
CSHOTPLOT - convert CSHOT data to files for CWP graphers
DZDV - determine depth derivative with respect to the velocity ",
FARITH - File ARITHmetic -- perform simple arithmetic with binary files
FTNSTRIP - convert a file of binary data plus record delimiters created
FTNUNSTRIP - convert C binary floats to Fortran style floats
GRM - Generalized Reciprocal refraction analysis for a single layer
H2B - convert 8 bit hexidecimal floats to binary
--More(3%)--
```

Hitting the space bar shows the rest of the page. The **suname** output shows every library function, shell script, and main program in the package, and may be too much information for everyday usage.

What is more common is that we might want a bit more information than a selfdoc, but not a complete listing. This is where the **sudoc** feature is useful. Typing

```
$ sudoc NAME
```

yields the **sudoc** entry of the program NAME.

For example we might be interested in seeing information about **suplane**

```
$ sudoc suplane
```

and comparing that with the selfdoc for the same program

```
$ suplane
```

As the number of SU programs you come in contact increases, you will find it useful to continually be referring to the listing from suname.

The **sudoc** feature is an alternative to Unix man pages. The database of sudocs is captured from the actual selfdocs in the source code automatically via a shell script, so these do not go out of step with the actual code, the way a separately written man page might.

## 4.3 Lab Activity #3 - Exploring the trace header structure

You may have noticed that the plotting programs seem to know a lot about the data you have been viewing. Yet, you have never been asked to give the number of samples per trace or the number of traces. For example

```
$ suximage < sonar.su   perc=99  &
```

shows a plot without being told the dimensions of the data.

But how did the program know the number of traces and the number of samples per trace in the data? The program knows because this, and all other SU programs read information from a "header" that is present on each seismic trace.

### 4.3.1 What are the trace header fields-sukeyword?

If you type:

```
$ sukeyword -o
```

you will obtain a listing of the file **segy.h**, which defines the SU trace header format. The term "segy" is derived from SEG-Y a popular data exchange standard established by the Society of Exploration Geophysicists (SEG) in 1975 and later revised in 2005. The SU trace header is largely the same as that defined for the SEG-Y format.

The first 240 bytes of each seismic trace in a SEG-Y dataset consist of this trace header. The data are always uniformly sampled in time, so the "data" portion of the trace, consisting of amplitude values only, follows immediately after the trace header. While it may be tempting to think of a seismic section as an "array" of traces, in the computer, these traces simply follow one after the other.

The part of the listing from sukeyword that is relevant at this point is

```
...skipping
typedef struct { /* segy - trace identification header */

int tracl; /* Trace sequence number within line
```

```
   --numbers continue to increase if the
   same line continues across multiple
   SEG Y files.
 */

int tracr; /* Trace sequence number within SEG Y file
   ---each file starts with trace sequence
   one
 */

int fldr; /* Original field record number */

int tracf; /* Trace number within original field record */

int ep; /* energy source point number
   ---Used when more than one record occurs
   at the same effective surface location.
 */

int cdp; /* Ensemble number (i.e. CDP, CMP, CRP,...) */

int cdpt; /* trace number within the ensemble
   ---each ensemble starts with trace number one.
 */

short trid; /* trace identification code:
-1 = Other
         0 = Unknown
 1 = Seismic data
 2 = Dead
 3 = Dummy
 4 = Time break
 5 = Uphole
 6 = Sweep
 7 = Timing
 8 = Water break
 9 = Near-field gun signature
10 = Far-field gun signature
11 = Seismic pressure sensor
12 = Multicomponent seismic sensor
- Vertical component
13 = Multicomponent seismic sensor
- Cross-line component
```

```
14 = Multicomponent seismic sensor
- in-line component
15 = Rotated multicomponent seismic sensor
- Vertical component
16 = Rotated multicomponent seismic sensor
- Transverse component
17 = Rotated multicomponent seismic sensor
- Radial component
18 = Vibrator reaction mass
19 = Vibrator baseplate
20 = Vibrator estimated ground force
21 = Vibrator reference
22 = Time-velocity pairs
23 ... N = optional use
(maximum N = 32,767)

Following are CWP id flags:

109 = autocorrelation
110 = Fourier transformed - no packing
     xr[0],xi[0], ..., xr[N-1],xi[N-1]
111 = Fourier transformed - unpacked Nyquist
     xr[0],xi[0],...,xr[N/2],xi[N/2]
112 = Fourier transformed - packed Nyquist
       even N:
     xr[0],xr[N/2],xr[1],xi[1], ...,
xr[N/2 -1],xi[N/2 -1]
(note the exceptional second entry)
     odd N:
     xr[0],xr[(N-1)/2],xr[1],xi[1], ...,
xr[(N-1)/2 -1],xi[(N-1)/2 -1],xi[(N-1)/2]
(note the exceptional second & last entries)
113 = Complex signal in the time domain
     xr[0],xi[0], ..., xr[N-1],xi[N-1]
114 = Fourier transformed - amplitude/phase
     a[0],p[0], ..., a[N-1],p[N-1]
115 = Complex time signal - amplitude/phase
     a[0],p[0], ..., a[N-1],p[N-1]
116 = Real part of complex trace from 0 to Nyquist
117 = Imag part of complex trace from 0 to Nyquist
118 = Amplitude of complex trace from 0 to Nyquist
119 = Phase of complex trace from 0 to Nyquist
121 = Wavenumber time domain (k-t)
```

```
122 = Wavenumber frequency (k-omega)
123 = Envelope of the complex time trace
124 = Phase of the complex time trace
125 = Frequency of the complex time trace
130 = Depth-Range (z-x) traces
143 = Seismic Data, Vertical Component
144 = Seismic Data, Horizontal Component 1
145 = Seismic Data, Horizontal Component 2
146 = Seismic Data, Radial Component
147 = Seismic Data, Transverse Component
201 = Seismic data packed to bytes (by supack1)
202 = Seismic data packed to 2 bytes (by supack2)
*/

short nvs; /* Number of vertically summed traces yielding
   this trace. (1 is one trace,
   2 is two summed traces, etc.)
 */

short nhs; /* Number of horizontally summed traces yielding
   this trace. (1 is one trace
   2 is two summed traces, etc.)
 */

short duse; /* Data use:
1 = Production
2 = Test
 */

int offset; /* Distance from the center of the source point
   to the center of the receiver group
   (negative if opposite to direction in which
   the line was shot).
 */

int gelev; /* Receiver group elevation from sea level
   (all elevations above the Vertical datum are
   positive and below are negative).
 */

int selev; /* Surface elevation at source. */

int sdepth; /* Source depth below surface (a positive number). */
```

```
int gdel; /* Datum elevation at receiver group. */

int sdel; /* Datum elevation at source. */

int swdep; /* Water depth at source. */

int gwdep; /* Water depth at receiver group. */

short scalel; /* Scalar to be applied to the previous 7 entries
   to give the real value.
   Scalar = 1, +10, +100, +1000, +10000.
   If positive, scalar is used as a multiplier,
   if negative, scalar is used as a divisor.
 */

short scalco; /* Scalar to be applied to the next 4 entries
   to give the real value.
   Scalar = 1, +10, +100, +1000, +10000.
   If positive, scalar is used as a multiplier,
   if negative, scalar is used as a divisor.
 */

int  sx; /* Source coordinate - X */

int  sy; /* Source coordinate - Y */

int  gx; /* Group coordinate - X */

int  gy; /* Group coordinate - Y */

short counit; /* Coordinate units: (for previous 4 entries and
for the 7 entries before scalel)
   1 = Length (meters or feet)
   2 = Seconds of arc
   3 = Decimal degrees
   4 = Degrees, minutes, seconds (DMS)

In case 2, the X values are longitude and
the Y values are latitude, a positive value designates
the number of seconds east of Greenwich
or north of the equator
```

```
In case 4, to encode +-DDDMMSS
counit = +-DDD*10^4 + MM*10^2 + SS,
with scalco = 1. To encode +-DDDMMSS.ss
counit = +-DDD*10^6 + MM*10^4 + SS*10^2
with scalco = -100.
*/

short wevel; /* Weathering velocity. */

short swevel; /* Subweathering velocity. */

short sut; /* Uphole time at source in milliseconds. */

short gut; /* Uphole time at receiver group in milliseconds. */

short sstat; /* Source static correction in milliseconds. */

short gstat; /* Group static correction  in milliseconds.*/

short tstat; /* Total static applied  in milliseconds.
   (Zero if no static has been applied.)
*/

short laga; /* Lag time A, time in ms between end of 240-
   byte trace identification header and time
   break, positive if time break occurs after
   end of header, time break is defined as
   the initiation pulse which maybe recorded
   on an auxiliary trace or as otherwise
   specified by the recording system */

short lagb; /* lag time B, time in ms between the time break
   and the initiation time of the energy source,
   may be positive or negative */

short delrt; /* delay recording time, time in ms between
   initiation time of energy source and time
   when recording of data samples begins
   (for deep water work if recording does not
   start at zero time) */

short muts; /* mute time--start */
```

```
short mute; /* mute time--end */

unsigned short ns; /* number of samples in this trace */

unsigned short dt; /* sample interval; in micro-seconds */

short gain; /* gain type of field instruments code:
1 = fixed
2 = binary
3 = floating point
4 ---- N = optional use */

short igc; /* instrument gain constant */

short igi; /* instrument early or initial gain */

short corr; /* correlated:
1 = no
2 = yes */

short sfs; /* sweep frequency at start */

short sfe; /* sweep frequency at end */

short slen; /* sweep length in ms */

short styp; /* sweep type code:
1 = linear
2 = cos-squared
3 = other */

short stas; /* sweep trace length at start in ms */

short stae; /* sweep trace length at end in ms */

short tatyp; /* taper type: 1=linear, 2=cos^2, 3=other */

short afilf; /* alias filter frequency if used */

short afils; /* alias filter slope */

short nofilf; /* notch filter frequency if used */
```

```
short nofils; /* notch filter slope */

short lcf; /* low cut frequency if used */

short hcf; /* high cut frequency if used */

short lcs; /* low cut slope */

short hcs; /* high cut slope */

short year; /* year data recorded */

short day; /* day of year */

short hour; /* hour of day (24 hour clock) */

short minute; /* minute of hour */

short sec; /* second of minute */

short timbas; /* time basis code:
1 = local
2 = GMT
3 = other */

short trwf; /* trace weighting factor, defined as 1/2^N
   volts for the least significant bit */

short grnors; /* geophone group number of roll switch
   position one */

short grnofr; /* geophone group number of trace one within
   original field record */

short grnlof; /* geophone group number of last trace within
   original field record */

short gaps; /* gap size (total number of groups dropped) */

short otrav; /* overtravel taper code:
1 = down (or behind)
2 = up (or ahead) */
....
```

```
/* cwp local assignments */
float d1; /* sample spacing for non-seismic data */

float f1; /* first sample location for non-seismic data */

float d2; /* sample spacing between traces */

float f2; /* first trace location */

float ungpow; /* negative of power used for dynamic
   range compression */

float unscale; /* reciprocal of scaling factor to normalize
   range */

int ntr;  /* number of traces */

short mark; /* mark selected traces */

        short shortpad; /* alignment padding */


short unass[14]; /* unassigned--NOTE: last entry causes
   a break in the word alignment, if we REALLY
   want to maintain 240 bytes, the following
   entry should be an odd number of short/UINT2
   OR do the insertion above the "mark" keyword
   entry */

...

float  data[SU_NFLTS];

} segy;
```

Not all of these header fields get used all of the time. Some headers are more important than others. The most relevant fields to normal SU usage are the header fields **tracl**, **tracr**, **dt**, **cdp**, **offset**, **sx**, **gx**, **sy**, **gy**, and **delrt**.

To see the header field ranges on **sonar.su**, **radar.su**, and **seismic.su** type

```
$ surange < sonar.su
```

```
584 traces:
tracl    1 584 (1 - 584)
cdp      1 584 (1 - 584)
muts     75
ns       3000
dt       100

$ surange < radar.su
501 traces:
tracl    1 501 (1 - 501)
tracr    1 501 (1 - 501)
trid     1
ns       463
dt       800
hour     11
minute   3 33 (3 - 33)
sec      0 59 (41 - 7)


$ surange < seismc.su
801 traces:
tracl    1200 2000 (1200 - 2000)
tracr    67441 115081 (67441 - 115081)
fldr     594 991 (594 - 991)
tracf    1 8 (2 - 2)
ep       700 1100 (700 - 1100)
cdp      1200 2000 (1200 - 2000)
cdpt     1 8 (2 - 2)
trid     1
nhs      57 60 (60 - 60)
gelev    -10
selev    -6
scalel   1
scalco   1
sx       18212 28212 (18212 - 28212)
gx       15000 25000 (15000 - 25000)
counit   3
mute     48
ns       601
dt       4000
```

In each case, where four numbers appear, these are the minimum and maximum values in the header followed by the first and last values in the data panel

You may use **sukeyword** to determine the meaning of any of the header field "keywords" seen here via

```
$ sukeyword   key
```

where "key" is the specific keyword. For example

```
$ sukeyword   tracl
```

returns

```
...
        int tracl;      /* Trace sequence number within line
                           --numbers continue to increase if the
                           same line continues across multiple
                           SEG Y files.
                         */
...
```

The first field **int** tells us that this is defined as type "integer" in the header. The short description is the SEG's definition for this field. This can be a big deal. Ofttimes users will want to define decimal values for the header fields.

Please note that the keyword names we use here are not an industry standard, but are peculiar to SU. These are an invention of Einar Kjartannson, the author of the original suite of programs call SY, that later became the basis of the SU package.

## 4.4 Concluding Remarks

Every data processing package has help features and internal documentation. None of these are usually perfect, and all are usually aimed at people who already understand the package. Look for the help features and demos of a package.

When receiving a dataset, the most important questions that a scientist can ask about a dataset that he or she receives are: "What is the format of the data?" "Are the data uniformly sampled?" For seismic data: "Have the headers been set?" and "What are ranges of the the header values?". "Do the header values make sense?"

Note also, that data coming in from the field, frequently requires that the headers be set in the data. Transferring header information from seismic observers logs into seismic trace headers is called "setting geometry." Setting geometry can be one of the biggest headaches in preparing data for processing.

Vendors may remap the SEG-Y header fields both in terms of the meaning of the header field and with respect to the data type. Obtaining a "header map" of data when you obtain seismic data can prevent confusion and save you a lot of work.

When receiving data on tape, remember that "tape reading is more of an art than a science." It is best to ask for data in a format you can use, rather than allow someone else to dictate that format to you.

# Chapter 5

# Lab Activity #4 - Migration/Imaging as depth conversion

Geophysical imaging, often called "migration" in the seismic context, is an example of a general topic called "inverse-scattering imaging." Simply stated, inverse scattering imaging is the process of "making pictures with echos." We have all encountered examples of this in our daily lives. Our eyes operate by making images of the world around us from scattered light. Medical ultrasound uses the echos of high frequency sound waves to image structures within the human body. Ultrasound is also used in an industrial setting for nondestructive testing (NDT). Seismic prospectors look for oil using the echos of seismic waves. Earthquake seismologists determine the internal structure of the deep earth with echos of waves from earthquakes. Near surface investigators use the echos of ground penetrating radar waves to image objects in the shallow subsurface.

## 5.1 Imaging as the solution to an inverse problem

Acoustic and elastic waves echo off of jumps in the wavespeed and/or the density of the medium. In the case of electromagnetic scattering, the signal is coming from a volume of material or a layer, rather than a boundary between layers, which has a differing conductivity from the surrounding material.

In each case, the propagating wave impinges on the boundary at some angle, and is reflected from the boundary at an angle determined by the *law of reflection* for the medium. For scalar waves, which is to say waves that do not experience mode conversion, the angle of incidence equals the angle of reflection. For elastic waves, the angle of reflection is a function of the angle of incidence and of the velocities and densities of the media on either side of the reflector.

The scattered wave therefore carries information about both the orientation of the reflector and its location. Thus, an image formed from such data is a solution to an inverse problem wherein the wavespeed of the medium and the location and orientation

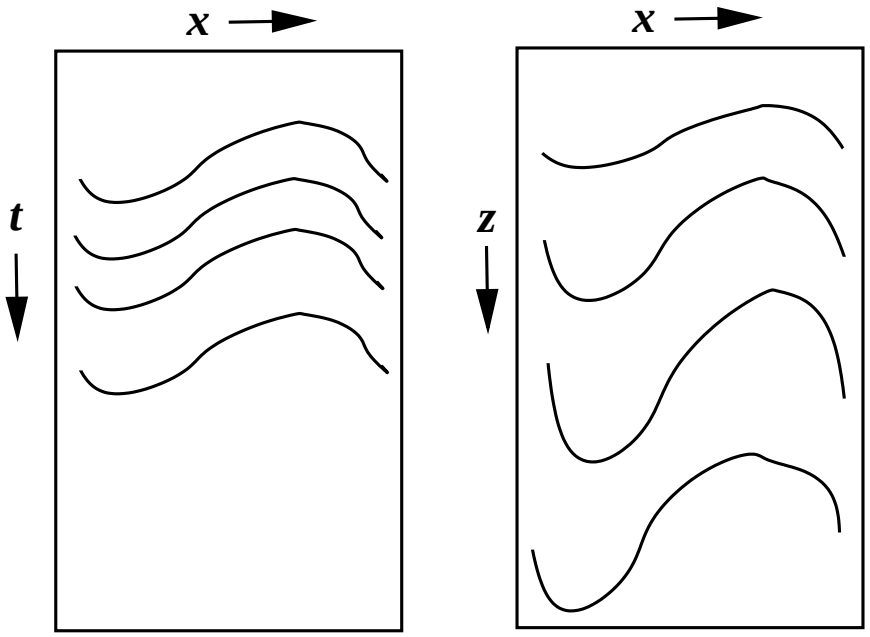


Figure 5.1: Cartoon showing the simple shifting of time to depth. The spatial coordinates $\boldsymbol{x}$ do not change in the transformation, only the time scale $t$ is stretched to the depth scale $z$. Note that vertical relief looks greater in a depth section as compared with a time section.

of the reflector are the unknown variables being solved for.

## 5.2 Inverse scattering imaging as time-to-depth conversion

In geophysics there are three common types of inverse-scattering imaging techniques that may be encountered. These are "sonar," "ground penetrating radar (GPR)," and "reflection seismic." In each case a species of wave is introduced into the subsurface. This wave is reflected off of structures within the Earth and travels back up to the surface of the Earth where it is recorded. In the raw form, the coordinates of the data consist of the spatial coordinates of the recording position and traveltime, which may be represented as the ordered triple of numbers $Data(x_1, x_2, t)$.

It is implied that some form of processing is needed to convert data collected in the input coordinates of space and time $Data(x_1, x_2, t)$ into an image in the output coordinates that are purely spatial $DepthImage(y_1, y_2, y_3)$ or are new spatial coordinates and a "migrated time coordinate" $TimeImage(y_1, y_2, \tau)$. When the output is in space and migrated time, we call the process "time migration" and the output a "time section". When the output is in purely spatial coordinates, we call the process "depth migration" and the output a "depth section". Each type of section is found useful in exploration seismic.

Thus, for our "migration as depth conversion" we will consider the final step of processing as a process that converts the data from $Data(y_1, y_2, \tau)$ to data in $DepthImage(y_1, y_2, y_3)$ in purely spatial coordinates.

The simplest cases of such processing occur when the output spatial coordinates on the recording surface are such that $y_1 = x_1$ and $y_2 = x_2$. Then the remaining problem is to "trade time for depth". Often the symbol $z$ is used to represent depth, with $z$ increasing positively as we go deeper into the earth.

Clearly, special circumstances are needed for this simple case to exist. Effectively, such an imaging problem is one dimensional. This type of problem may result from the construction of synthetic well logs from migrated seismic data or making depth sections from migrated time sections.

Sonar and GPR data usually have the attribute that the same piece of equipment is used as both source and receiver. Furthermore, this source-receiver array is likely highly directional, forming a beam of energy that travels straight down into the Earth. Because the scattering occurs from roughness in the structures ("rough surface scattering") of the subsurface and, owing to the strength of the sources involved, we may consider the reflection to have occurred from directly below the receiver.

To perform time-depth conversion, we need to know something about the velocities of the subsurface.

## 5.3 Time-to-depth with suttoz ; depth-to-time with suztot

The simplest approach to depth conversion is to use a simple velocity profile expressed as a function of time $v(t)$. How can we have velocity as a function of time? The idea is intuitive. We expect the image to show reflectors. These reflectors are the boundaries between media of different wavespeeds. Given auxiliary information about geology, well logs or the result of seismic velocity analysis, we expect to be able to relate arrivals on the seismic section to specific depth horizons, for which, in turn, we have wavespeed information.

## 5.4 Time to depth conversion of a test pattern

To see what the problem of time-to-depth and depth-to-time is all about, we may try **suttoz** on a test pattern made with suplane

```
$ suplane > junk.su
$ suttoz < junk.su t=0.0,.15,.2 v=1500,2000,3000 > junk1.su
$ suxwigb < junk.su title="test pattern" &
$ suxwigb < junk1.su title="depth section" &
```

The program suztot has been provided to apply depth-to-time conversion, as the inverse of sutotz. Because we know the values of the velocity that were used, we must

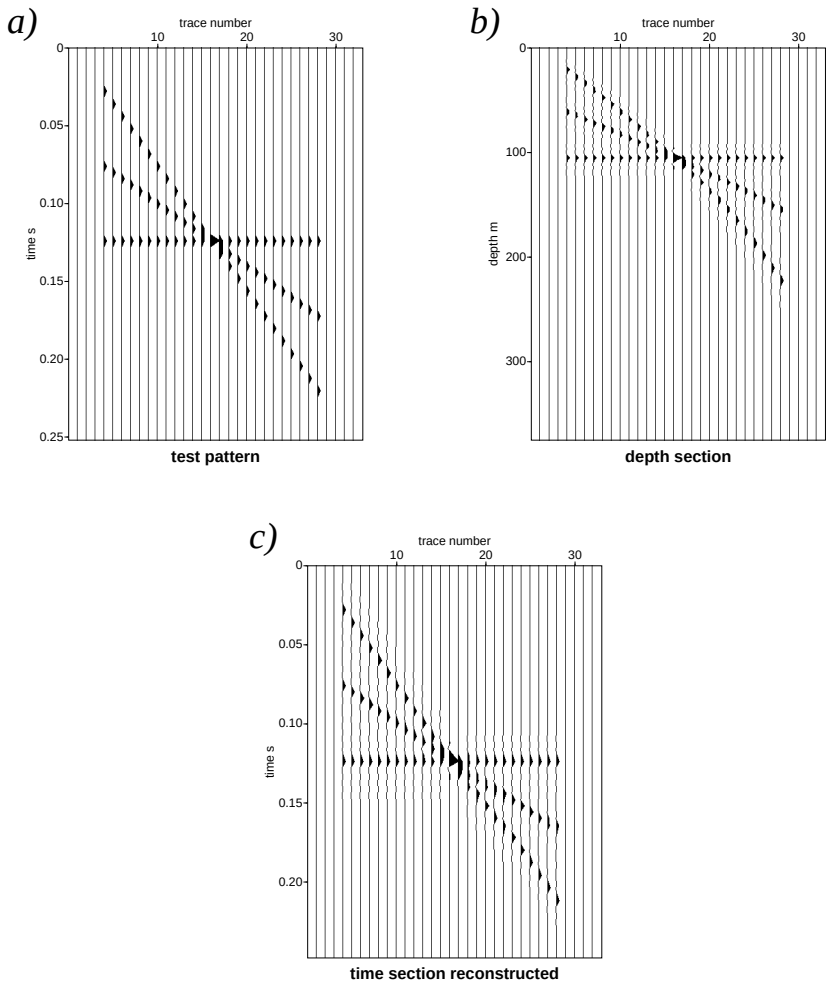


Figure 5.2: a) Test pattern. b) Test pattern corrected from time to depth. c) Test pattern corrected back from depth to time section. Note that the curvature seen depth section indicates a non piecewise-constant $v(t)$. Note that the reconstructed time section has waveforms that are distorted by repeated sinc interpolation. The sinc interpolation applied in the depth-to-time calculation has not had an anti-alias filter applied.

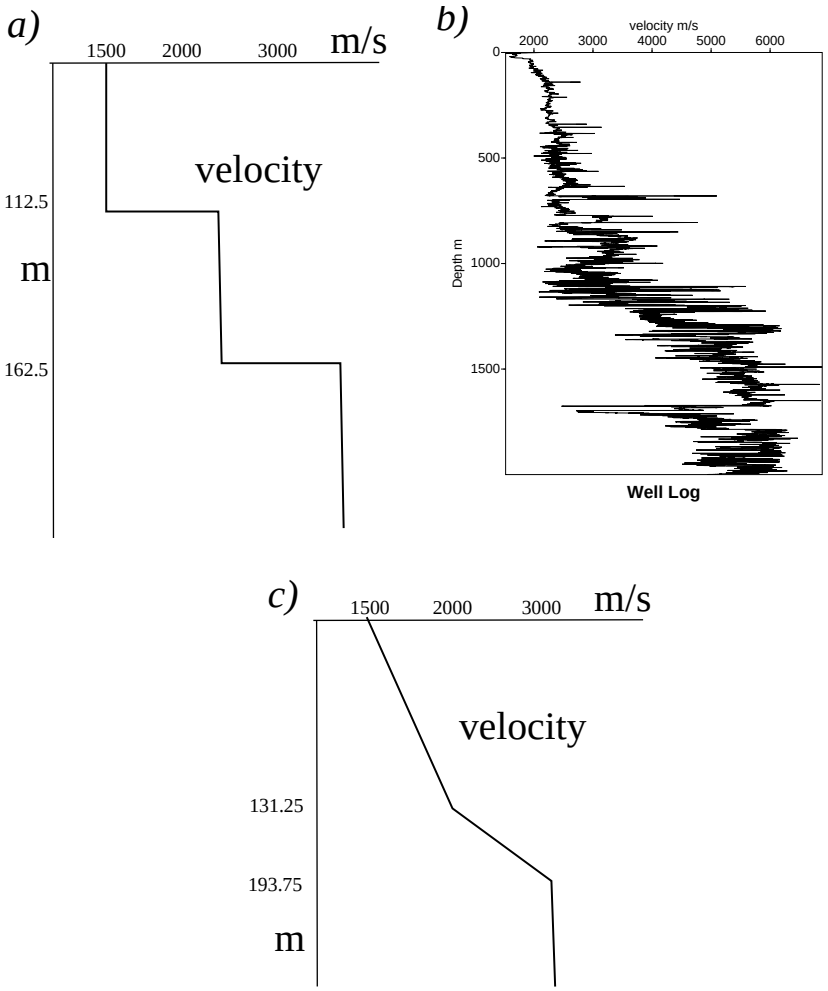


Figure 5.3: a) Cartoon showing an idealized well log. b) Plot of a real well log. A real well log is not well represented by piecewise constant layers. c) The third plot is a linearly interpolated velocity profile following the example in the text. This approximation is a better first-order approximation of a real well log.

try to figure out the depths Z1, Z2, and Z3, necessary to undo the operation

```
$ suztot < junk1.su  z=Z1,Z2,Z3 v=1500,2000,3000 > junk2.su
$ suxwigb < junk2.su title="time section reconstructed" &
```

Please note, you don't literally type "z=Z1,Z2,Z3" what you want is to find three numbers representing depths to substitute in for Z1, Z2, and Z3. The first value $Z1 = 0$.

You will notice that on the **junk1.su** data, the picture does not start getting distorted until after about depth 105. This gives a clue as to the place where the faster speeds kick in.

You will further notice that the **junk2.su** data does not look very much like the junk.su data. The first think that you should notice is that the original junk.su data only goes to about .24 seconds, but the junk2.su data goes to more than .5 seconds.

It is a good idea to see if the header values have changed by using surange. The original data shows

```
$ surange < junk.su
32 traces:
tracl    1 32 (1 - 32)
tracr    1 32 (1 - 32)
offset   400
ns       64
dt       4000
```

whereas the depth converted data has a greater number of samples

```
$ surange < junk1.su
32 traces:
tracl    1 32 (1 - 32)
tracr    1 32 (1 - 32)
trid     30
offset   400
ns       126                <------ ns has increased!!!
dt       4000
d1       3.000000
```

and finally, the depth-to-time converted data

```
$ surange < junk2.su
32 traces:
tracl    1 32 (1 - 32)
tracr    1 32 (1 - 32)
offset   400
ns       63                 <-------- ns is now 63
dt       4000
```

shows ns=63, rather than the original ns=64 samples.

### 5.4.1 How time-depth and depth-time conversion works

The way that this works is simple. Each sample of the data is a function of time. We have velocities to use for each time value. If the velocity is constant, then the process of time to depth conversion is more of a relabeling process than a calculation. However, for situations where the velocity varies as we go to later times in the data, we have to deal with the fact that the sample spacing of the time-to-depth shifted data changes as the velocity changes. Indeed, constant or piecewise-constant profiles rarely accurately represent wavespeed variation in the real earth.

The depth is calculated for each sample, but because we want the output to be uniformly sampled, we have to interpolate the missing depth values. This interpolation may be done many ways, but in this program it is done by fitting a sinc function (*sinc interpolation*) to the data points. The bandwith of this sinc function is the the band from 0 to the Nyquist frequency of the data. When resampling to a greater number of samples, the Nyquist frequency of the output is greater than the Nyquist frequency of the input, so there is no possibility of aliasing. However, if we subsample data, the potential for aliasing exists.

To repeat the test, we should be setting **nt=64** to force the number of samples to be the same on both input and output

```
$ suplane > junk.su
$ suttoz < junk.su t=0.0,.15,.2 v=1500,2000,3000 > junk1.su
$ suztot < junk1.su nt=64 z=Z1,Z2,Z3 v=1500,2000,3000 > junk2.su
$ suxwigb < junk.su title="test pattern" &
$ suxwigb < junk1.su title="depth section" &
$ suxwigb < junk2.su title="reconstructed time section" &
```

The time-to-depth may be improved by truncating the additional values

```
$ suwind itmax=64 < junk1.su | suxwigb title="time to depth" &
```

where **suwind** has been used to pass only the first 64 samples of each trace.

The short answer is that while the time-to-depth and depth-to-time conversions are ostensibly simply piecewise linear operations in this simple example, the fact is that there is the potential for errors to be introduced by the interpolation process. These errors may make only approximately invertible process.

The main problem is deciding how the $v(t)$ and $v(z)$ functions are to be interpolated. As is seen in Fig 5.3 constant step models seen in cartoon well log diagrams does not accurately depict the complexity of actual well logs. The simplest approximation to a real well log is a piecewise continuous curve, with **piecewise linear** being the simplest curve. That is, we assume a functional form of $v(t) = mt + b$ for velocity as a function of time.

For the example of $t = 0.0, .15, .2 \qquad v = 1500, 2000, 3000$ in the region from $t = 0.0$ to $t = .15$ the velocity profile would be given by $v_1(t) = (500/.15)t + 1500$, and in the region from $t = .15$ to $t = .2$, the velocity profile is given by $v_2(t) = (1000/.05)t + 2000$. Calculating the values of the depths $Z1, Z2, Z3$, we see trivially that $Z1 = 0$ and that integrating the two equations above yields $Z2 = 131.25$ and $Z3 = 193.75$, respectively.

## 5.5 Sonar and Radar, bad header values and incomplete information

Most likely, depth conversion for sonar and radar requires simply knowing the speed of sound in water, and the speed of light, respectively. This sounds simple, and if we had all of the information in a neat and consistent form, it would be.

The first complication comes from the fact that SU is a *seismic* package. When non-seismic data are used in a seismic package, often the time sampling interval must be scaled to store the data. The reason for this is to save storage space in the header, the creators of the SEG-Y data format chose the time sampling interval **dt** not to be a floating point number, but rather as an unsigned short integer. On a 32 bit machine, the size of the largest value that an unsigned short can take on is 65535. Thus, scaling is necessary.

Usually, these scale factors are multiples of 10. Try doing depth conversion on the sonar and radar data, using values you know for the speed of sound

```
$ suttoz v=SPEED_OF_SOUND_IN_WATER < sonar.su | suximage perc=99 &
```

and the speed of light

```
$ suttoz v=SPEED_OF_LIGHT < radar.su | suximage perc=99 &
```

respectively.

The speed of light is $2.998 \times 10^8 m/s$. The speed of sound in water is $1500 m/s$. Likely, the correct values to use in each case will be off by some multiple of 10, owing to the fact that the natural frequencies available for radar and sonar are not in the same band as those used for seismic data.

If we type

```
$ sukeyword dt
...
        unsigned short dt;      /* sample interval; in micro-seconds */
..
```

we see that the time sampling interval, dt, is expressed in microseconds. Seismic frequencies range from a few Hz, to maybe 200 hz, but likely are not up into the kilohertz range, unless some special survey is being conducted. Sonar frequencies likely range ten's of kilohertz to hundreds of kilohertz. Radar operates in the megahertz range. So, it is common for the user to fake the units on the time sampling interval so as to fit the requirements of a seismic code.

## 5.6 The sonar data

The "sonar.su" file is one of the profiles collected by Dr. Henrique Tono of Duke University in a special laboratory setting.

According to a personal communication by Dr. Tono, the "geologic setting" of the sonar data is thus

> "The deposits and images were produced at the Saint Anthony Falls Lab of the University of Minnesota. Here, experimental stratigraphy is produced under precisely controlled conditions of subsidence, base level, and sediment supply. By superimposing optical images of the sectioned deposits on seismic images, we can directly observe the ability of seismic profiling to distinguish different geological features.
>
> The experimental basin is 5 m by 5 m (25 m2) and 0.61 m deep. Sediment and water were mixed in a funnel and fed into the basin at one corner. This produced an approximately radially-symmetrical fluvial system, which averaged 2.50 m from source to shoreline. The edges of the basin were artificially roughened in order to direct the channels away from the walls. The "ocean level" was maintained through a variable-discharge siphon located in the opposite corner of the basin. Though we imposed a gradual base-level rise, in order to simulate subsidence, the shoreline maintained a constant position through the experiment."

Dr. Tono goes on to describe the experimental layout:

> "The outgoing pulse is generated with a Prototype JRS DPR300 (Pulser/Receiver), which drives a 900-volt square pulse into the transducer. It is set to a pulse/receive frequency of 100 Hz, with an input gain of 30 dB in echo mode. The high pass filter is set at 20 KHz, and the low pass filter at 10 MHz. A Gage-Applied Compuscope 1602 digitizer computer card (16 Bit, 2 Channel card with acquisition memory of 1 Million samples) is used to perform the A/D conversion, and the data is displayed on a computer screen by means of GageScope 3.50. It is digitally recorded on the computer hard disk. A sample rate of 2.5 MS/s is chosen (Nyquist frequency=1.25 MHz). It is then re-formatted to SEG-Y and processed with Seismic Unix.
>
> The data were acquired with a $5mm$ shotpoint and station interval (zero offset), and $1cm$ separation between lines."

In the directory /cwpscratch/Data1 you will find a number of JPEG format files depicting the experimental setting described by Dr. Tono.

The file "dsc01324.su" is an SU format file version of the image DSC01324.JPG, cropped to remove parts of the image that are not the cross section. This is not exactly the cross section of the data sonar.su, but it gives the idea. Rarely, are we able to slice into the actual model in this fashion.

## 5.7 Homework Problem - #2 - Time-to-depth conversion of the sonar.su and the radar.su data. Due Thursday 8 Sept 2011

Find the necessary velocities to permit the correct time-to-depth conversion of the **sonar.su** and **radar.su** data. You will need to figure out the appropriate units, because it is not possible for these non-seismic datasets to have an accurate representation of the time sampling interval represented in the trace header field **dt**. Make sure that you give a justification explaining why your choice of the appropriate power of 10 scaling factor is likely the correct one. Remember that the depth scale on you output data should make sense.

## 5.8 Concluding Remarks

When receiving software, either that is given to us, or that which we purchase, it is important to try to figure out what assumptions are built into the software. One way to do that is to try the software out on test patterns.

When receiving data, it is important to know everything that you can possibly know about the data, such as the spacing of the traces, the time sampling interval, any processing that has been applied.

When explaining seismic imaging to non-geophysicists, it is tempting to say that seismic imaging is "sort of like sonar". However, sonar is a rough-surface-scattering imaging, whereas seismic is a "specular" or mirror-reflection-scattering imaging. In rough-surface scattering, the image may, indeed, be formed by "straight down and straight back" reflections. In seismic, this is rarely the case. We must take offset between the source and receiver into account. In seismic, there are also rough-surface contributions. These are the diffractions we look for on stacked data.

In the early days of seismic (well into the 1930s) there were practitioners of the seismic method, who thought that seismic was like sonar and expected that seismic datasets should be "data images."

# Chapter 6

# Zero-offset (aka poststack) migration

The first reflection seismic experiment as applied to the petroleum exploration was conducted by physicist John Clarence Karcher in Oklahoma in 1921. Oklahoma was the center of the US oil industry at that time. It is clear from reading documents from that era that the expectations of reflection seismic methods were that the results should be similar to sonar. That is, the expectation was that the signal would travel straight down into the subsurface, reflect off of a few structures, and then travel straight back up to be recorded. There was no expectation of off-vertical reflections.

We of course know that this is not the case. By the 1930s many geophysicists were well aware of the geometrical issues at the heart of proper seismic interpretation. With the formation of the Society of Exploration Geophysicists in 1930, followed by the first issue of the Society's journal *Geophysics* the proper usage of seismic data for geologic interpretation became known to the geophysical community.

In Figure 6.1 we see the classical "bowtie" feature seen over a syncline. To the early interpreter of seismic data, this diagram would not have constituted an image of the subsurface, but rather a source of geometrical data (such as dip) pertaining the subsurface reflector.

Another notion that became apparent is that parts of the data on the seismic traces is displaced from its "correct" position by the properties of wave propagation. Assuming that all reflections are normal incidence for this zero-offset geometry, it is clear that parts of the bowtie originate from higher positions on the sides of the syncline. Thus, the notion of "migrating" those arrivals to their correct location became an important idea for interpretation. Because the seismic data were analog rather than digital, such corrections would naturally be applied graphically.

While graphical migration techniques had been applied since the 1930s, the first notable technical paper describing this technique was published by J. G. (Mendel) Hagedoorn in 1954. This paper is important because Hagedoorn's description of the migration process inspired early digital computer implementations of migration.

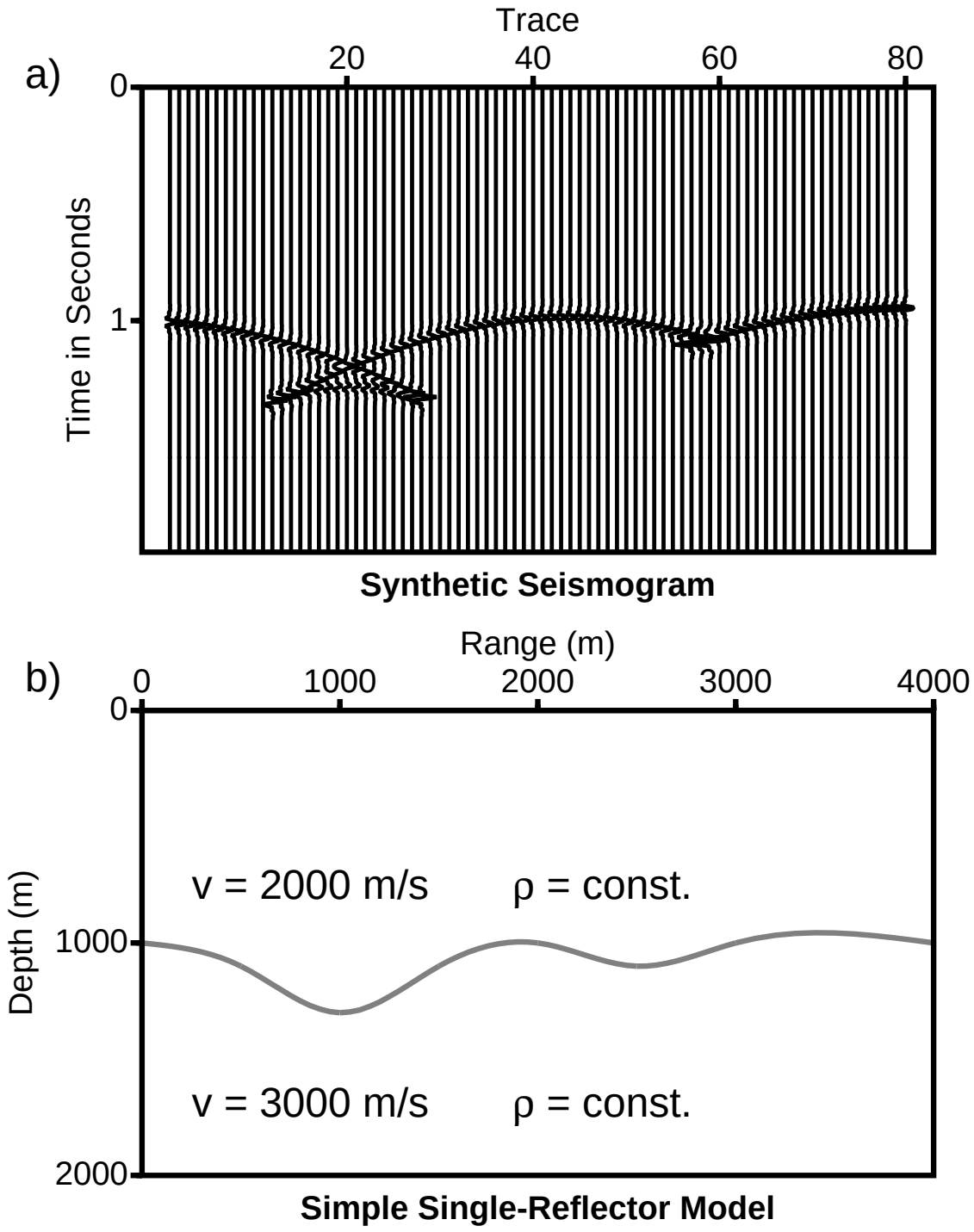


Figure 6.1: a) Synthetic Zero offset data. b) Simple earth model.

## 6.1 Migration as reverse time propagation.

One way of looking at migration is as a reverse time propagation. The idea may be visualized by running the output from a forward modeling demo in reverse time. Do the following, noting that you need to replace "yourusername" with your actual username on the system, so that the items are copied to your personal scratch area

```
$ cp /cwpscratch/Data1/syncline.unif2 /scratch/yourusername/Temp1
$ cp /cwpscratch/Data1/XSyncline /scratch/yourusername/Temp1
```

Now

```
$ cd /scratch/yourusername/Temp1
```

If you type:

```
$ more syncline.unif2
   0         0
4000         0
   1    -99999
   0       1000.
 500.      1100.
 1000.     1300.
 2000.     1000.
 2700.     1100.
 3200.     1000.
 4000.     1050.
   1.   -99999
```

you will see the input data for a wavespeed profile building program called **unif2**. The contents of this file define two boundaries in a velocity model. The data for the two boundaries is separated by the values

```
   1.   -99999
```

The values in the column on the left are horizontal positions and the values on the right are depths. This model defines the same simple syncline model seen in Fig 6.1. We now look at the contents of the shell script **XSyncline**

```
$ more XSyncline

#! /bin/sh
# Shell script to build velocity profiles with unif2

# input parameters
modelfile=syncline.unif2
velfile=syncline.bin
```

```
n1=200
n2=400
d1=10
d2=10

# use unif2 to build the velocity profile
unif2 <$modelfile method=$i ninf=2 nx=$n2 nz=$n1 v00=1000,2000 \
ninf=1 method=spline  > $velfile

# view the velocity profile on the screen
ximage < $velfile  wbox=400 hbox=200 n1=$n1 n2=$n2 d1=$d1 d2=$d2 \
 wbox=800 hbox=400  legend=1 title="Syncline model" label1="depth m" \
label2="distance m " units="m/s" &

# provide input for sufdmod2
xs=1000 zs=10 hsz=10 vsx=1000 verbose=2
vsfile="vseis.su" ssfile="sseis.su" hsfile="hseis.su"
tmax=3.0 mt=10
label1="Depth m"
label2="Distance m"

# perform finite difference acoustic modeling to generate data
# for a single shot in the
sufdmod2 < $velfile nz=$n1 dz=$d1 nx=$n2 dx=$d2 verbose=1 \
        xs=$xs zs=$zs hsz=$hsz vsx=$vsx hsfile=$hsfile \
        vsfile=$vsfile ssfile=$ssfile verbose=$verbose \
        tmax=$tmax abs=1,1,1,1 mt=$mt |
suxmovie  clip=1.0 \
        title="Acoustic Finite-Differencing" \
        windowtitle="Movie" \
        label1=$label1 label2=$label2 \
        n1=$n1 d1=$d1 f1=$f1 n2=$n2 d2=$d2 f2=$f2 \
        loop=1 sleep=20000  -geometry 800x400 &

exit 0
```

You may run the demo by typing:

```
$ XSyncline
```

The result shows the wavespeed profile for the model. This is similar to the "simple" model that will be discussed later in the these notes. A movie showing snapshots of the wavefield will begin. Watch the wavefront of the energy from the shot expand. You may stop and restart the movie by pressing the far right mouse button. Of interest are the frames at which the first reflections begin. As the movie progresses, you will see

the reflected field progress as the reflection point propagates along the reflector surface. Indeed, from viewing this movie, we can see why an integral over the reflector surface, called the "Kirchhoff modeling formula" is a way of modeling the reflected field.

Note that you only see wavefronts, there is nothing like a "ray" to be seen. A ray is the trajectory taken by a point on a wavefront. Second, notice that the "bowtie" forms as the caustic in the propagating wavefield.

The movie will run in a loop. You may stop the movie by pushing the right mouse button. You may reverse the movie by pressing the middle mouse button. Effectively, running the field backward in time is "reverse-time migration." In seismic data, we do not have a record of the down-traveling field. All we have is the record of that part of the reflected field that hits the surface of the earth where there are geophones. The migration process finds the place where the downtravelling field and the reflected field overlay—the reflector surface. One way of looking at migration is that we would like to cross-correlate the down-traveling field with the time-reversed reflected field. The place where these fields correlate is at the reflector surface.

You may also see what the seismic data looks like recorded at the surface of the earth model by viewing the file **hseis.su** via

```
$ suximage < hseis.su perc=99
```

to see the direct arrival and the bowtie-shaped reflected arrival.

Finally you may change the depths in the model by editing the file **syncline.unif2**, or change the location of the source to see what varying these quantities changes in the data. You may slow down the movie by increasing the value of the **sleep=** parameter.

## 6.2 Lab Activity #5 - Hagedoorn's graphical migration

The purpose of this lab example is to migrate the simple data in Figure 6.1a) by Hagadoorn's graphical method. These synthetic data represent the zero-offset reflection seismograms recorded over the undulating reflector model in Figure 6.1b). The wavespeed in the upper medium is assumed to be 2000 m/s, and the data are drawn in such a way that 1.0 s two way time is equivalent to 1000 m of distance. Thus, the time scale translates into a depth scale that is compatible with the horizontal scale.

If we draw a circle centered at time $t = 0$ of a given seismic trace and passing through a given seismic arrival, we have sketched all possible reflection points from which the seismic arrival could have originated. These circles are the same as the incident field seen in the seismic movie. If we recall, seismic migration finds the place where the incident field interacts with the reflected field—the reflector surface.

When similar circles are drawn for every arrival on every trace, the result is a collection of circles whose envelope delineates the reflector. See Fig 6.3 for an idea of what this should look like.

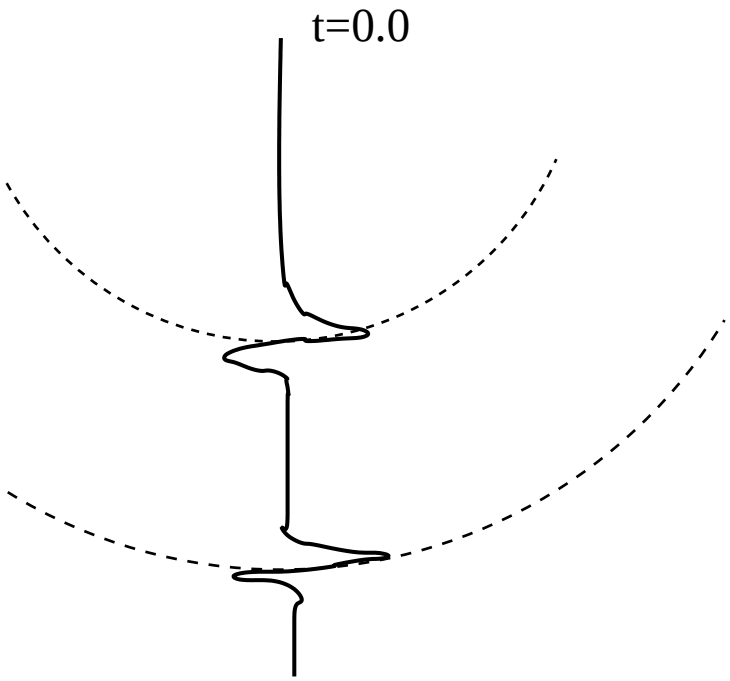


Figure 6.2: The Hagedoorn method applied to the arrivals on a single seismic trace.

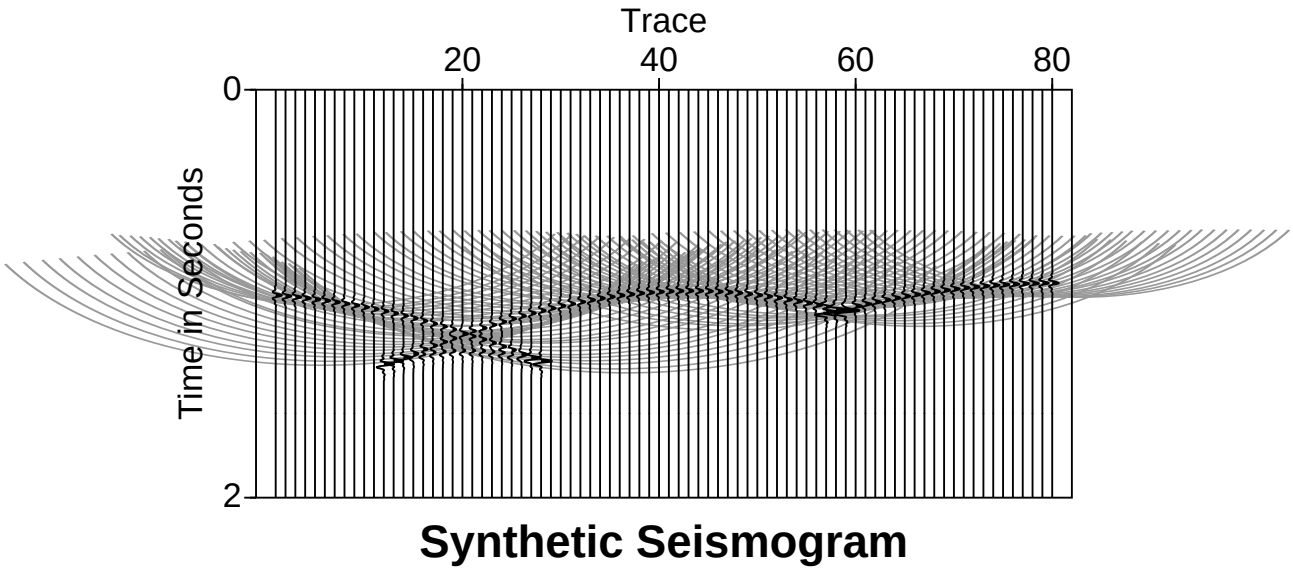


Figure 6.3: Hagedoorn's method applied to the simple data of Fig 6.1. Here circles, each centered at time $t = 0$ on a specific trace, pass through the maximum amplitudes on each arrival on each trace. The circle represents the locus of possible reflection points in $(x, z)$ where the signal in time could have originated.

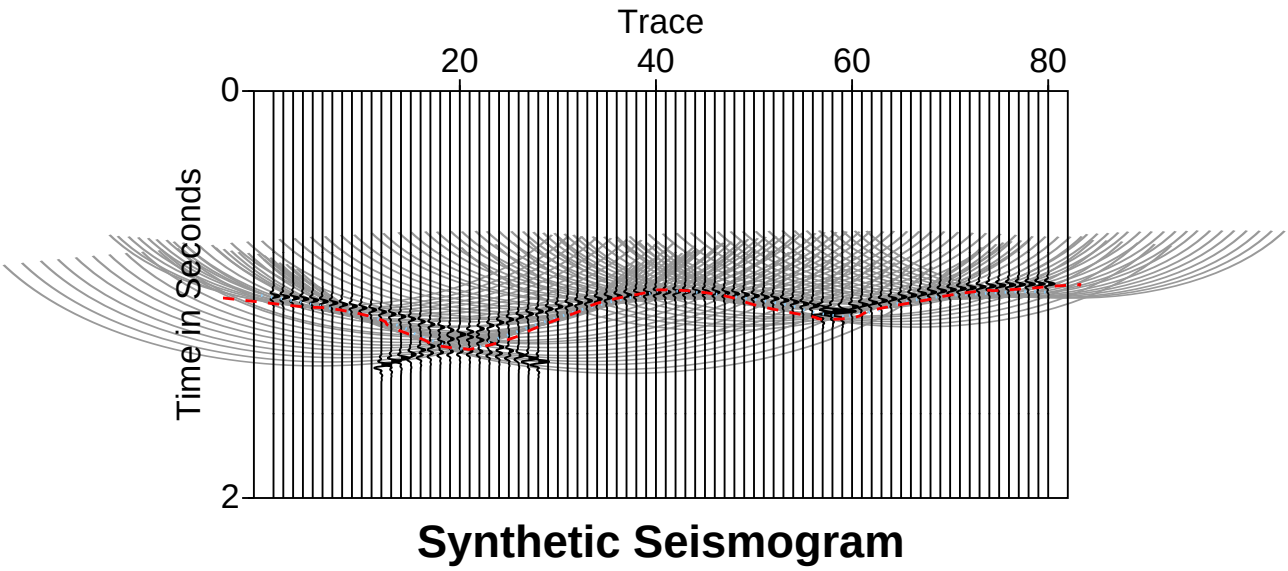


Figure 6.4: The dashed line is the interpreted reflector taken to be the envelope of the circles.

Mathematically this method of migration may be thought of as the reconstruction of the reflector by defining the *tangent vectors* of the reflector. What then, are the circles we have drawn? The answer can by found by looking at Figure 6.5. For our 2D constant-wavespeed example, all solutions of the wave equation, which is to say *all wavefronts*, can be found by passing a horizontal plane through the cone in Figure 6.5. Both physical (causal) solutions (the positive $t$ cone) and the nonphysical (anti-causal) solutions (the negative $t$ cone) are depicted. We use the causal cone for modeling, and the anti-causal or reverse-time cone for migration.

To see what a given circle means in Hagadoorn's method, we may look at the reverse time cone in Figure 6.6. We may think of the curve on the $t = 0$-plane as the locus of all possible positions from which the reflection originated, or we may think of this as the wavefront of the backward-propagated wave.

If we were to apply the Hagedoorn method on the computer, we might consider creating for each seismic trace a panel of seismic traces replicating our original seismic arrivals, but on a semicircular pattern. "Spraying" out our seismic data for each trace along the respective Hagedoorn circle would yield one new panel of traces for each seismic trace. Our 80 traces would then become 80 panels of sprayed traces. We would then sum the corresponding traces on each panel. Constructive interference would tend to enhance the region near the reflector, and destructive interference would tend to eliminate everything else, revealing only the reflector. Does this method work? Yes, but it is subject to interference errors, if the data are not densely sampled in space.

Because a point at $(\xi, \tau)$ represents an impulse in the $(x, t)$ space, corresponding

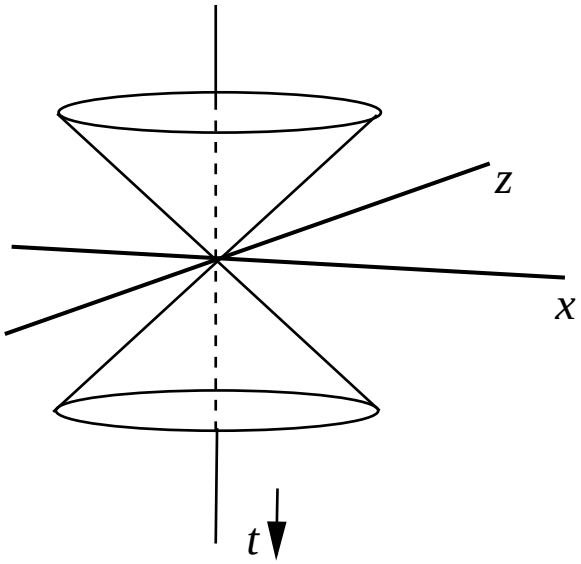


Figure 6.5: The light cone representation of the constant-velocity solution of the 2D wave equation. Every wavefront for both positive and negative time $t$ is found by passing a plane parallel to the $(x, z)$-plane through the cone at the desired time $t$. We may want to run time backwards for migration.

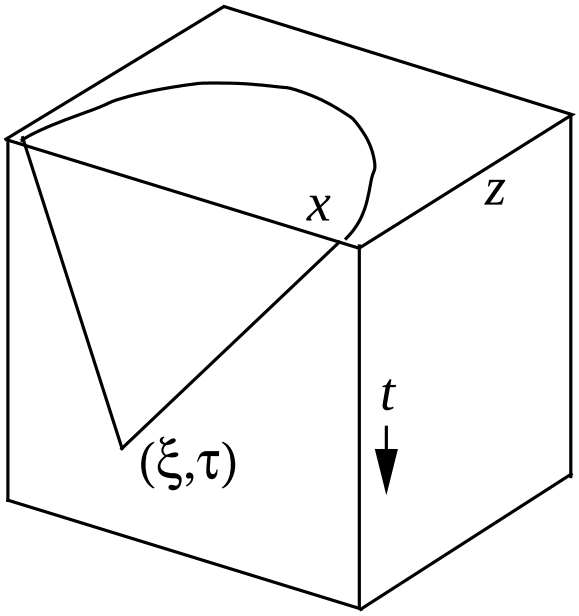


Figure 6.6: The light cone representation for negative times is now embedded in the $(x, z, t)$-cube. A seismic arrival to be migrated at the coordinates $(\xi, \tau)$ is placed at the apex of the cone. The circle that we draw on the seismogram for that point is the set of points obtained by the intersection of the cone with the $t = 0$-plane.

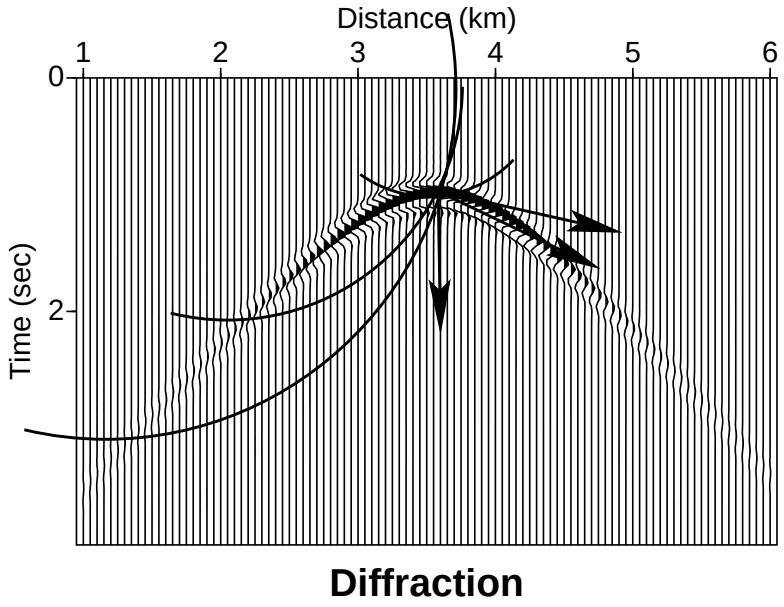


Figure 6.7: Hagedoorn's method of graphical migration applied to the diffraction from a point scatterer. Only a few of the Hagedoorn circles are drawn, here, but the reader should be aware that any Hagedoorn circle through a diffraction event will intersect the apex of the diffraction hyperbola.

circle drawn in Hagadoorn's method may be thought of as the *impulse response* of the migration operation.

## 6.3 Migration as a Diffraction stack

Another approach to migration is immediately apparent. If we apply Hagedoorn's method to the diffraction from a point scatterer, then we observe that the scatterer is reconstructed. However, tangent vectors are not defined with regard to a point scatter. Instead, it must be the *vector from the source/receiver position to the scatterer* that is being reconstructed. In other words, the *reflected ray vector* is the distinguished vector associated with the imaging point. For a reflector surface, this is the *perpendicularly-reflected ray vector*. See Figure 6.7.

Furthermore, we might ask: why is it necessary to draw Hagedoorn's circles at all? Suppose that we were to sum over all possible diffraction hyperbolae. Then the largest arrivals would exist only where a hyperbola we sum on hits a hyperbola in the data. The sum would then be placed at a point at the apex of the hyperbola passing through our data. This type of migration is referred to as a *diffraction stack*. We sum or "stack" data, but we do this over a diffraction curve. Furthermore the output need not be a

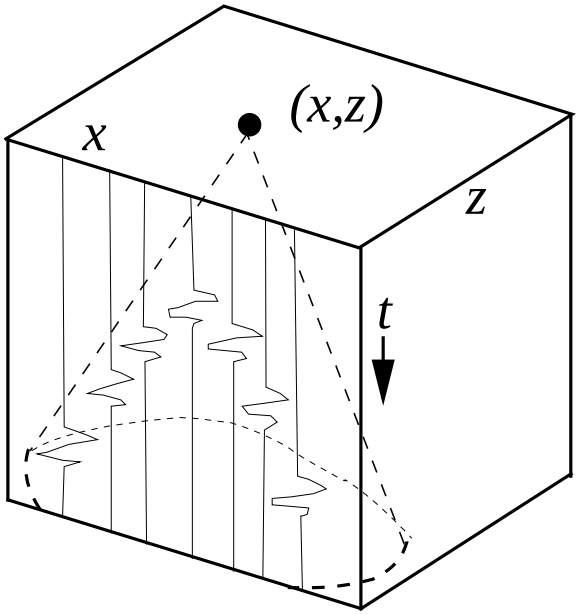


Figure 6.8: The light cone for a point scatterer at $(x, z)$. By classical geometry, a vertical slice through the cone in $(x, t)$ (the $z = 0$ plane where we record our data) is a hyperbola.

depth section, but could be a *time section*.

A useful diagram for understanding the diffraction stack is the light cone diagram in Figure 6.8. A *light cone* is the representation of the surface where solutions of the wave equation live. The scatterer is located at the point $(x, z)$. Time increases downward. A horizontal slice through the cone reveals the circular wavefronts that are the circles drawn in Hagedoorn's method. A vertical slice through the cone in $(x, t)$ reveals the hyperbola that is the characteristic shape of a diffraction in a constant wavespeed medium.

## 6.4 Migration as a mathematical mapping

Another diagram that reveals migration as a type of data transformation or *mapping* may be seen in Figure 6.9. Here, we see that the impulse response of the migration operator is a circular curve in constant wavespeed media.

The diffraction in $(x, t)$ may be thought of as the "impulse response" of the modeling operation that made the data from a point at $(x, z)$. Migration by diffraction stack, therefore, consists of selecting a point $(x, z)$, modeling the diffraction curve in $(x, t)$, and then summing through the data over this curve. Note that this must be done for every output point to make the image.

Figure 6.9 represents more than migration. Going from **a)** to **b)** is Hagedoorn's migration method. Going from **c)** to **d** is the diffraction stack migration method. If however, we reverse directions, mapping from from **b)** to **a)** or from **d)** to **c** then we are *modeling* or doing data-based **de-migration**, which is the inverse of migration. The idea then is that modeling is the forward process and migration is the inverse operation.

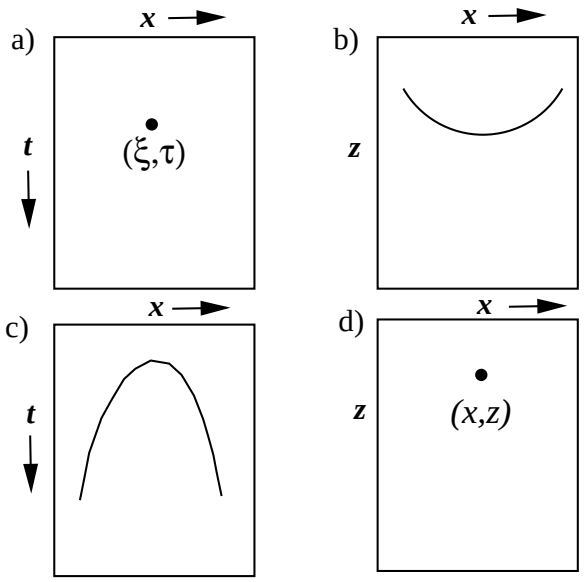


Figure 6.9: Cartoon showing the relationship between types of migration. a) shows a point in $(\xi, \tau)$, b) the impulse response of the migration operation in $(x, z)$, c) shows a diffraction, d) the diffraction stack as the output point $(x, z)$.

## 6.5 Concluding Remarks

The notion of the value and motivation of using seismic data has changed through the history of seismic methods. Originally, seismic data were used to find estimates of depth of perhaps a single important horizon. As the technique developed, the depth to and dip of a specific target reflector was found. Most notably was Frank Rieber's "dip finder." The "dip finder" was a recording system that was effectively an analog computer that delivered an estimate of depth and dip for stronger reflectors. These data were then used for drawing geologic cross-sections. In fact, Frank Rieber's dip finder was doing something similar to a variety of migration called "map migration."

As the petroleum and natural gas industry evolved, so did the importance of the seismic method. The technique started out as an aid in interpretation, becoming later an "imaging technology." Today, seismic migration is viewed by many as the "solution to an inverse problem" wherein recorded seismic data are used as input to solve for the reflectivity of the reflectors, as well as other important material parameters that characterize lithology.